3-21-2018

AEVUM: Personalized Health Monitoring System

Abhishek Swaminathan
axs9312@rit.edu

AEVUM

Personalized Health Monitoring System

By

Abhishek Swaminathan

A Thesis
In Partial Fulfillment of Requirements for the Degree of
Master of Fine Arts in Industrial Design
School of Design, Department of Industrial Design
College of Imaging Arts and Sciences

Rochester Institute of Technology
Rochester, NY

Approved on: 03/21/2018

COMMITTEE APPROVAL

____ Date:

Mr. Stan Rickel
Associate Professor, Industrial Design;
Graduate Coordinator

____ Date:

Dr. Esa Rantanen
Associate Professor, Department of Psychology

Abstract

Advancement in the field of sensors and other portable technologies have resulted in a bevy of health monitoring devices such as blue-tooth and Wi-Fi enabled weighing scales and wearables which help individuals monitor their personal health. This collected information provides a plethora of data points over intervals of time that a primary care physician can utilize to gain a holistic understanding of an individual's health and provide a more effective and personalized treatment. A drawback of the existing health monitoring devices is that they are not integrated with the professional medical infrastructure. With the wealth of information collected, it is also not feasible for a physician to look through all the data to obtain relevant information or patterns from multiple health monitoring systems. Therefore, it would be beneficial to have a single platform of hardware devices to monitor and collect data and a software application to securely store the collected information, identify patterns for analysis, and summarize the data for the physician and the patient.

The aim of this study was to design and develop an unobtrusive, user friendly system, **Aevum**, which would integrate technology, adapt itself to changes in consumer behavior and integrate with the existing healthcare infrastructure to help an individual monitor their health in a customized manner. Aevum is a multi-device system consisting of a smart, puck-shaped hardware product, a wristband and a software application available to the patient as well as the physician. In addition to monitoring vitals such as heart rate, blood pressure, body temperature and weight, Aevum can monitor environmental factors that affect an individual's health and uses personalized metrics such as precise calorie intake and medication management to monitor health. This allows the user to personalize Aevum based on their health condition. Finally, Aevum identifies patterns of anomalies in the collected data and compiles the information which can be accessed by the physician to assist in their treatment.

Table of Contents

Table of Figures

List of Tables

Chapter I - Introduction

The Patient-Doctor Conversation

There is nothing that scares a person than a visit to the family physician, be it for a regular, pre-planned annual check-up or an unplanned trip when they are ill. The medical encounter between a patient and a doctor has long been studied by conversation analysts as an arena of naturally occurring conversations. [1] As medical organizations and hospitals move towards patient-centered care from disease-centered care, it becomes important to remove the various pain points from this important interaction. Good communication with the patient is as beneficial for the doctors as it is for the patient. As the communication improves with the doctor, patients tend to open-up and commit themselves to the process ahead.[1] This leads to a satisfactory result for both, leading to an efficient use of medical services and patients better adhering to the post treatment regimen prescribed by the doctor. [1]

Patient's point of view

Patient satisfaction, as a concept, is increasingly gaining traction in medical research and literature, reflecting a developing focus on patient-centered care.[1] Patients have certain expectations from their visit and when they depart, they cross reference their experience with these expectations to determine the quality of the medical encounter. It is only possible to satisfy a patient by either meeting or exceeding their expectations.[2] It makes sense to start by addressing the question, "Who is a patient?" A patient is referred to as "anyone voluntarily or involuntarily seeking medical care for a perceived condition of their health".[3]

The first major pain point for a patient starts from the point of booking an appointment with the doctor. The channels of communication to make an appointment have improved over the past few decades, from walking in and waiting to see the doctor, to calling and booking an appointment, to now; using various services on the internet to book appointments in a matter of seconds on your computer or smartphone.[4] There is a need to provide a lot of personal and medical information on forms, either while making the appointment or while at the doctor's office before the appointment. The patient must remember the symptoms which led them to believe that something is wrong, along with other information such as their family medical history, events leading up to the visit and information on the cause of their problem.

Waiting time at clinics plays a crucial role in determining patient satisfaction.[5] The average waiting time varies between 7 minutes to as much as 66 minutes in family practice doctor clinics; while it varies between 12 to 45 minutes in specialty doctor clinics.[6] The average cumulative wait time for all clinics, specialty or family practice across the United States is 18.5 minutes.[6] This causes incredible discomfort to someone who is already worried about their physical condition. This additional and unwarranted stress on the patient hinders their ability to communicate their symptoms clearly to the doctor.

Figure 1 Patient wait times for family practice and specialty doctors in mainland United States[6]

Doctor's point of view

A doctor is "any person who has undergone recognized training in biomedicine and has been authorized by society to practice it without restriction."[3] The doctors have to be prepared for a whole range of patients from children who do not possess the capacity to explain what is happening to them to the elderly, who need specialized treatment, expect empathetic care and concern for their well-being and require constant reassurance as well. The internet has not made it easy for the doctors either with an avalanche of home remedies and medical diagnosis available to people at the click of a button. Patients have their own expectation with regards to how much information they require from the doctor pre-appointment and compare this with the amount of information they receive post-appointment. They expect to be treated in a caring yet competent manner, while they also make a note of the physical appearance (clothes worn) and expressions of the nurses and doctors.[7] Each encounter at the clinic improves or deteriorates the quality of the patient's encounter and a doctor's approval is the sum of these interactions.[8]

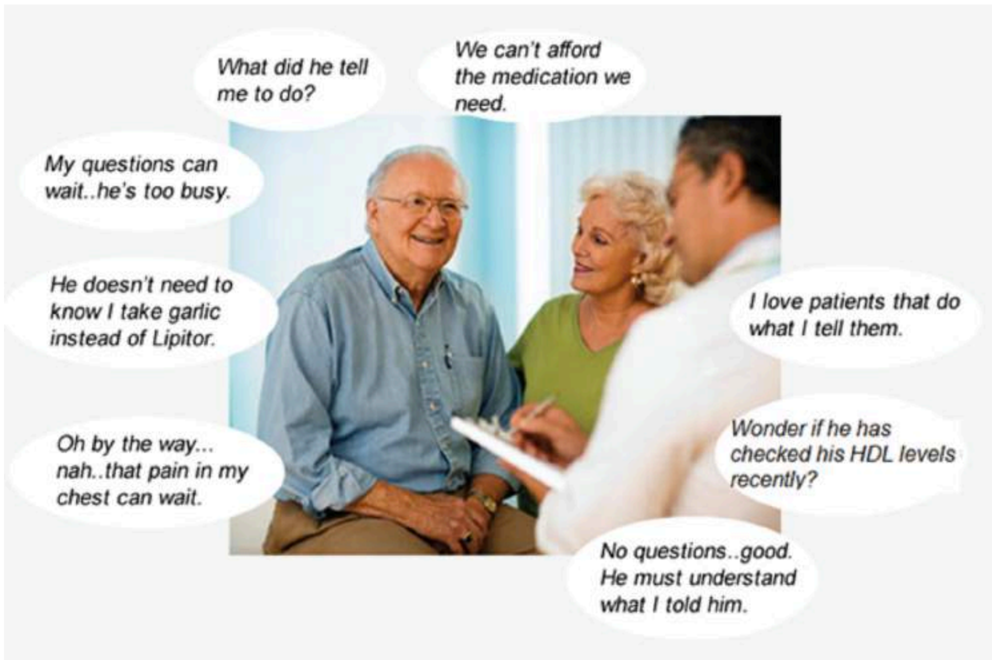

Figure 2 Illustration of a doctor-patient conversation

A study by Booth, Harrison, et al.[9], surveying close to 1600 patients in the Emergency ward and General Clinic of the Manchester Medical Hospital and University, showed that patient satisfaction, despite wait times exceeding 40 minutes to see the doctor, was high for two reasons: A) The highly satisfied patients made a note that they were constantly attended to by the nurse practitioners; who made them feel at ease and provided constant reassurance after reading the patients' vitals and B) The amount of time the doctor spent examining them and explaining the future course of action was comparable to the amount of time they waited.

The conclusions drawn from the research of Booth, Harrison, et al. [9] illustrates some very important points. They talk about personalized care and constant monitoring by the nurse practitioners. The patients were empowered when they were constantly provided information on their vitals by the nurses and constant reassurance helped put them at ease that the symptoms they were experiencing did not pose any apparent risk.

The push for personalized healthcare

Health insurance and healthcare costs have increased by almost 200% over the past 20 years.[10] Medical bills are a major factor in more than 60% of personal bankruptcy cases in the United States despite 75% of these cases involving individuals who had medical insurance coverage at the time.[11] Insurance in the United States has been intrinsically tied to an individual's job. Most insurance companies provide a discounted rate for companies who then take it from the employee's paycheck. Despite this access to affordable health insurance, almost 40% of working age Americans are currently paying out medical bill debt.[10] Moreover, because of the recession and increasing health insurance costs, the number of Americans who are uninsured has risen from 38 million to about 52 million in the past 5 years. [10]

Figure 3 Percentage of dollar spent on healthcare by the average American as of 2013. [10]

The rapid changes in health-care costs and insurance coverage are convincing corporations, insurance companies and health-care groups to encourage patients to take more control over their own health. Empowering the patient and democratizing medicine is the inevitable way forward for the field. The medical field has for long been incessantly evolving from within, slowly chipping away what we can call old medicine, creating a new one.[12]

The individuals born towards the end of the Baby Boom generation and all the generations behind them want to control their health-care more and are comfortable in using technology tools to do that. [13] About 23% of the American population will be 60 years or older by the year 2030. [11] Rising costs of assisted living facilities along with the fear of living in an unfamiliar location among unfamiliar people only increases the need for better personalized health monitoring. The fear of living in an assisted home facility for the elderly, along with the acceptance of technology among the baby boom generation has increased the need for in-home healthcare. [11]

Baby boomers will contribute to a growing medical crisis.[11] As lifespans increase and demographics shift, the number of adults requiring health care increases. Health care providers will come under immense strain as they will have to cater to a large population needing medical assistance combined with the rising cost of medical procedures. [11]

The market is filled with close to ten thousand devices and 40,000 mobile medical applications that monitor everything from blood pressure levels to brain wave pattern recognition.[14] About 65% of these devices are wearable and the rest are stand-alone (Blood pressure machines, weight scales, etc. are considered stand-alone).[12]

Figure 4 Example of a stand-alone smart device (iHealth Bluetooth blood pressure) available in the market

An Internet survey in December 2013[15] of close to 2000 people across different demographics showed that 7 in 10 Americans monitored at least one health indicator, with 60% of the respondents monitoring weight, diet and exercise and 33% monitoring blood pressure, blood glucose levels and sleep patterns. The same survey put forth an interesting statistic that only 46% of the people who tracked at least one measure ended up changing their approach to maintaining their health.[13]

Personalized health monitoring is most definitely the way forward. There has been a recent spurt in news articles about how information obtained from health monitoring devices such as Fitbit and Apple watch have been able to save an individual's life.[16] This news must be celebrated and looked upon as a stepping stone to create a health monitoring device or system that not only helps monitor several aspects of an individual's health and well-being but also integrates with the existing medical infrastructure.

The advent of the smartphone and wireless sensors has helped in the advancement of personalized health monitoring. With about 80% of the world's adult population in possession of a smartphone,[17] the next step is to enable the patients to generate data about their health and use machine learning, cloud computing and artificial intelligence to interpret it for them.

The data created by the number of devices on the market, results in an erratic dispersion of the data. Different modalities are measured by different devices and these devices exist in their own closed ecosystem. This problem, again, can be sorted by developing devices that feed into the existing medical infrastructure. [15]

The California Healthcare Foundation survey also noted that 60% of the population is still wary of personalized wrist bands and other measuring devices with respect to the security of their data, the accuracy of it and ease of use. [13] If they must be integrated with the existing healthcare infrastructure, it is imperative that health tracking devices be held to the highest security standards. Ability to safely dispose used and worn out devices should be made available.

As the study tries to traverse through this vast landscape of digital medicine in the hopes of empowering the patient and enhancing patient-doctor conversation with personalized health monitoring, it will look at how personalized health monitoring has evolved as an idea over time since its inception. Interviews with doctors, present and future consumers, to study the impact of the numerous health monitoring devices in the market were conducted as part of the research. The best-selling wearables in the market were benchmarked to understand their successes and limitations. This paper draw conclusions by conceptualizing a system that will help ease the patient-doctor conversation.

Chapter II – Painting A Picture

What is Personal Health Monitoring?

Personal Health Monitoring is where individuals use tools like sensors and other portable technologies to collect, process and display a wealth of personal data to help them monitor and manage all aspects of their personal health.[18]

History

The history of Personal Health monitoring traces back to the advent of Family Medicine in the mid-1800s.[19] A solo physician, informally trained by an older physician, would serve the entire family. The physician would set fractures, deliver babies, treat a multitude of illnesses and even help the dying.[20] The family physicians would know the patient's medical history including their allergies and the medication prescribed. This resulted in them also being their pharmacist.[21] The problem with family medicine was that there was no formal education or training for the physicians and there was a lot of 'quackery'.[22] This led to the establishment and incorporation of the American Medical Association over the turn of the century.

Family medicine continued to flourish well into the mid-20th century but things started to change in the 1960s.[18] The middle class was growing, families became nuclear and moved to the cities where hospitals were established and run by formally trained doctors.[18] Between 1930 and 1974, physicians, or "General Practitioners" as they came to be called in the late 20th century, practicing family medicine dropped from 83% to 18% and there was a concomitant increase in the number of specialty doctors. [17] Physicians and patients alike believed that the trend towards specialized care had fragmented the health care industry and weakened the patient-doctor relationship.[23] Dr. Lewis Smith, a general practitioner in Brooklyn, New York mentioned to Steven Dennis, "There are 57 different specialists to treat 57 different diseases but not one physician to take care of a patient."[23] There was a growing public outcry, especially in small town America, over fragmented medical care which lead to the creation of a 'specialty' called "Family Medicine." [23]

Gerteis et al. described a similar problem with the fragmentation of healthcare and called to move towards patient centered care. One of the solutions was, "Electronic Personal Health records."[24] A personal health record, as defined by the Federal Trade Commission, is an "electronic record of identifiable health information about an individual, that can be drawn from multiple sources and that is managed, shared and controlled by or primarily for the individual."[25]

Traditional personal health records (PHRs) trace back to the early 1930s. In this traditional method, the health care provider stored and maintained the patient's medical records. The health care provider would also make updates to the records as required. The system worked because people were not as mobile as they are now, and it helped with continuity of care of the individual.[26] The record would consist of the person's medical history, course of treatment in any previous visits and record any other communication with the provider. The maintenance of this record also helped in the protecting the legal rights and interests of both patients and providers.[27]

As people started becoming more mobile, towards the end of the century; it became apparent that PHRs on paper did not make much sense. Health care providers sprouted across the country and in the late 1950s with the discovery of X-rays, better pills to fight infection, penicillin and other scientific advancements, medicine was growing across the world. [25]

Medical tourism became a trend and continues to be a major source of revenue for many countries.[28] The technological advancement resulted in the fragmenting of an individual's medical records. A person would go to a specialist in Florida to treat a particular disease, while travelling to India to treat some other health condition.[28] The necessity to defragment a patient's medical history resulted in computerized or electronic medical records that could be carried by the patient or transferred by the hospital to any other provider in the country of treatment.[28] An electronic health record system was first implemented in Utah's Latter-Day Saints Hospital and later used by the military. [24] The huge IT corporations such as Microsoft came into the picture in the 1990s and developed standardized electronic health record software that ran on its Windows platform. [24]

It was not until 2007 that the United States government created an initiative to make electronic health records available to most Americans by 2014. This was a direct result of the lack of preparedness to Hurricane Katrina.[29] The victims of the Hurricane were unable to refill prescriptions and provide their new health care provider with their old diagnostic tests because their health records were paper-based and destroyed, or electronically stored at an inaccessible facility. This lead to the development and deployment of integrated data records.[29]

The legacy of President George Bush was carried forth by President Barack Obama and almost all Americans had access to a national electronic health record system by the end of 2014. This was considered as Personal Health Record 2.0.[29] Though there are multiple providers for electronic health records standardized to help the individual and the doctor understand what is happening with their health, problems persist with regards to the usability of the Personal Health Records. Patients have limited access to enter, maintain and disclose portions of their record and there is limited assistance provided to help the elderly, disabled and immigrant populations who use these records. [27]

Smart Healthcare

Joseph Schumpeter, who was the Finance Minister of Austria, termed creative destruction as this mutation that would completely revolutionize any industry, destroying the old school of thought while at the same time developing a new one.[30] The internet, especially the bandwidth of mobile connectivity available to us today coupled with advancements in wireless sensors, imaging and genomics, has created this super convergence of events creating a paradigm shift in healthcare.

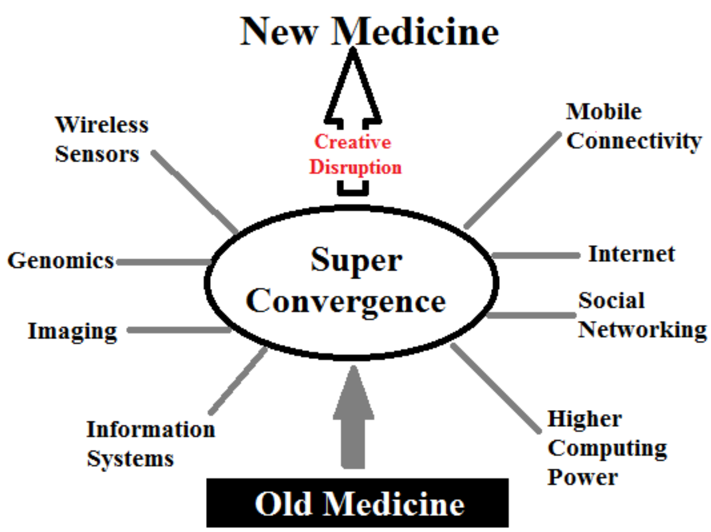

Figure 5 Illustration depicting the creative destruction of medicine

Within a decade, we have moved from desktop health monitoring devices to wearables monitoring the most acute health conditions. These devices have been able to lessen the burden on the healthcare infrastructure. The advancement in sensor technology has helped to miniaturize a number of devices for health monitoring.[31] Using the electrocardiogram as an example, the following figure illustrates how the core technology has been miniaturized from water buckets and vacuum tubes to table top and portable devices with transistors, and finally to wearable devices with integrated circuits.[32] It is possible that the device might evolve into a stretchable wearable fabric with organic electronics in the future.[33]

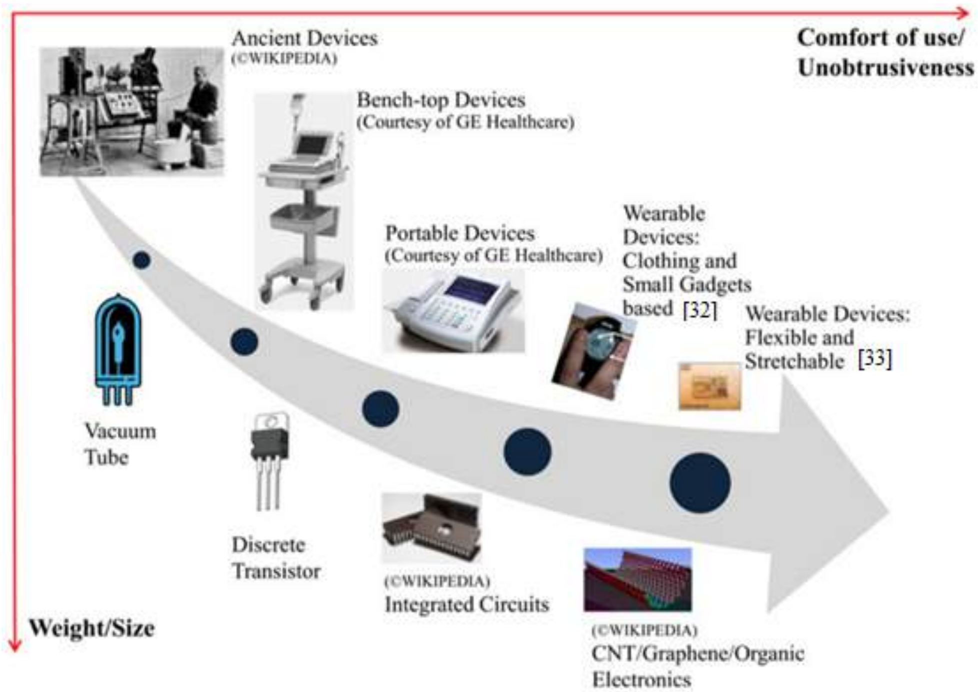

Figure 6 Graph showing the evolution of Electrocardiogram (ECG) machine with improvement in technology[31]

Google is developing a contact lens with sensors built on them to detect cataract growth, glaucoma, glucose levels and any increase in ocular power.[34] Sensors have been developed to study and recognize brain wave patterns[35], wireless electrocardiograph, percentage of oxygen and minerals in blood[36] among others. Sensors can be used to detect changes in behavioral patterns caused by the onset of an illness in patients.[37]

Gamification of sensors is a growing field, meant to collect important data on physical activity, movement, posture and calories burnt.[38] This has been helpful in getting people out and about. Physical activity in real life correlates to some reward in the virtual world. For example, Adidas placed a chip in running shoes, which measured the amount of physical activity. It added this information to a player created by the user in the EA Sports NBA Live game. The more the physical activity in real life, the higher the jump in attribute scores for the created player in the game.[39]

Imaging systems have improved tremendously over the past decade. High tech imaging systems are now built in with video game consoles such as Xbox and PlayStation. These imaging systems can detect the faintest change in a person's skin color, any bruises and several other physical features of the person. Imaging systems are currently being developed to measure the amount of light reflected by the body of a person. This can then help us to detect the body temperature and pulse rate at that point in time.[40]

The advancement in technology coupled with the growth in pervasive computing has meant that despite being widely used in clinical settings for many years, these devices can provide real time information by connecting with the existing widely available internet infrastructure.[41] It is now possible to facilitate a timely intervention to catastrophic health events such as a stroke or heart attack, if connected with the existing medical infrastructure.[42] This has been extremely useful in bringing expert treatment to rural and remote areas where it is not readily available.[42] In addition, unobtrusive and wearable health monitoring devices has helped people closely track their wellbeing, promoting an active and healthy lifestyle and facilitating the implementation of preventive measures at an earlier stage.[43]

The internet has caused a paradigm shift in our lives, and it has not missed out on health. Multiple forums of people discussing their health issues, symptoms and recovery schedule is available for everyone to see. The internet combined with mobile connectivity, social networking and cloud computing have been the real drivers of change in the healthcare industry. Information systems with complex algorithms built in, look through the data thrown out by millions of users and provide them with accurate personalized infographics on their health and well-being.

Chapter III – Research

Methodology

The research methodology while approaching this paper was to begin by benchmarking some of the more popular health monitoring devices in the market today. These include the Apple Watch, Nike Fuelband, Jawbone Up and the Fitbit Flex. The author of this study used the health monitoring devices to compare their parameters. It also goes on to conduct user research interviews with doctors and consumers to understand their perspective on health monitoring devices as well as figuring out their preference of metrics that they want tracked. Several studies were researched to understand; a) the importance of data in health monitoring, b) various experiments with health monitoring and c) the latest technology available to monitor personal health.

Benchmarking

The Nike Fuel Band

The Nike Fuel Band was launched in the month of January 2012 as an activity tracker. It consisted of a black polycarbonate band that was to be worn around the wrist. The data could be tracked live on a smartphone mobile application which was available on both the iOS App Store as well as the Android Play Store.

Figure 7 A Nike fuel band

The Nike Fuel band could be used to track the distance the person had run, the period of the physical activity, the time of day and the number of calories burnt during the physical activity.

The major positive point of the band and the app was the social life that came along with it. People basically competed against their friends and family who also had the band. This social life acted as a major motivator for the people using the band.

Nike, to increase the benefits of using the band regularly, included what they called NikeFuel

Points. NikeFuel Points could be used as a reward point while making a purchase in a Nike Store. This tied up the whole ecosystem perfectly. The biggest problem however was that the band did not do much beyond just counting your steps and measuring the number of miles one ran/walked during the day. There was no benefit to the band other than pushing you to run or walk while wearing it every day.

It appeared that this band did not provide the user with any more functionality than a regular activity tracker, except for the social motivation. Data upload via Bluetooth worked flawlessly; however, there was no analysis done on the data obtained. The battery lasted the listed 8 days which was a positive. However, considering the limited functionality of the device, this was not a selling point.

Figure 8 Screenshots submitted by Nike for NikeFuel app in the iOS App Store

The Jawbone Up

The Jawbone Up is a rubber coated wristband launched by the American company Jawbone in the year 2011. The wristband was accompanied by a smartphone application available in the iOS app store and Android play store. The Up was marketed as the quintessential health monitoring wearable device.

Figure 9 A Jawbone Up band

The Jawbone Up did not just track the distance covered on a run/walk by an individual and count the steps taken during the day, it also analyzed sleeping patterns, adjusted itself to various workout activities such as the treadmill, elliptical, weights and stretches to determine the number of calories burned during a workout session. It also measured and adjusted the calories burnt while playing sports such as swimming, tennis, badminton and golf.

The Up app went one step further by measuring the calorie intake of a person based on the meals they ate during the day. This was a helpful feature for the people who watched what they ate or for those who were on a controlled diet.

The app also had a social life like the NikeFuel band app. Here you controlled what you shared with your friends and family and could also graphically compare the physical activity of two of your friends or your friends with yourself.

The biggest drawback while using this device was however, the manual input one had to provide for almost every activity. Except for measuring the distance run or walked and the calories burnt during that run, nothing was ubiquitous. The activities performed, or the sport played had to be manually entered during or before the workout.

Even the food intake had to be mentioned in detail, for the app to analyze and determine the number of calories consumed. It did not have all the ingredients that went into specific diets and it became tedious to input the entries for every single meal. It provided no qualitative analysis on the all the data it gathered over a period. It did provide some graphs on the workouts when the information was manually input, and the sleep pattern recognition worked as described by the manufacturer. The battery lasted for close to 15 days and charging via the 3.5 mm jack was helpful.

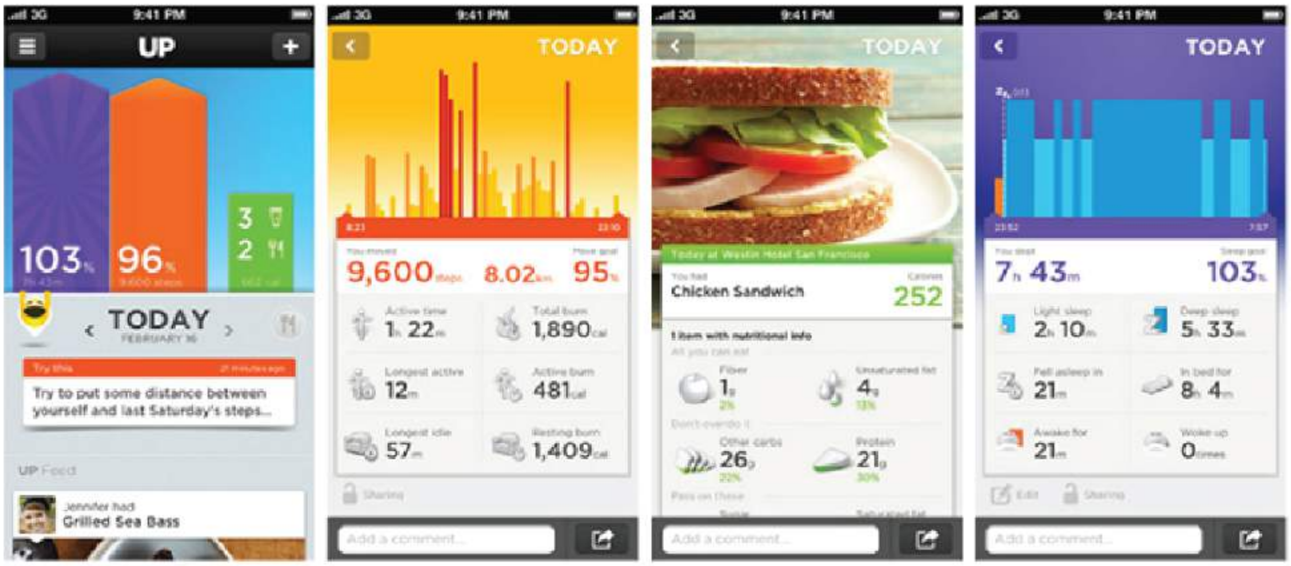

Figure 10 App screenshots provided by Jawbone in the iOS App Store

A key point against the Jawbone is that, it is just an activity tracker that cannot provide more input to the doctor than whether a person is active or not.

Fitbit Flex

The Fitbit Flex is an anodized rubber wrist band launched by the American company Fitbit in January 2013. The Fitbit flex is accompanied by a smartphone application available on the iOS App Store and Android Play Store.

Figure 11 A Fitbit Flex band

The Fitbit Flex has features pretty like the Jawbone Up. The Flex can measure the distance you ran and measures the calories burnt during a physical activity. It can also adjust the calculations to measure the calories burnt for various activities such as working out in the gym or while swimming, playing tennis or during a round of golf. The Flex can also measure and analyze your sleep patterns to ensure you are getting just the right amount of REM sleep needed.

It has one distinct feature that is not available in either the Nike Fuel Band or the Jawbone Up and that is the heart rate monitor. This is a very important feature especially when you are talking about integrating a device with the medical infrastructure. In fact, there have been stories on how the emergency room doctors used the heart rate graph from a man's Fitbit flex to understand what happened and save his life.[44]

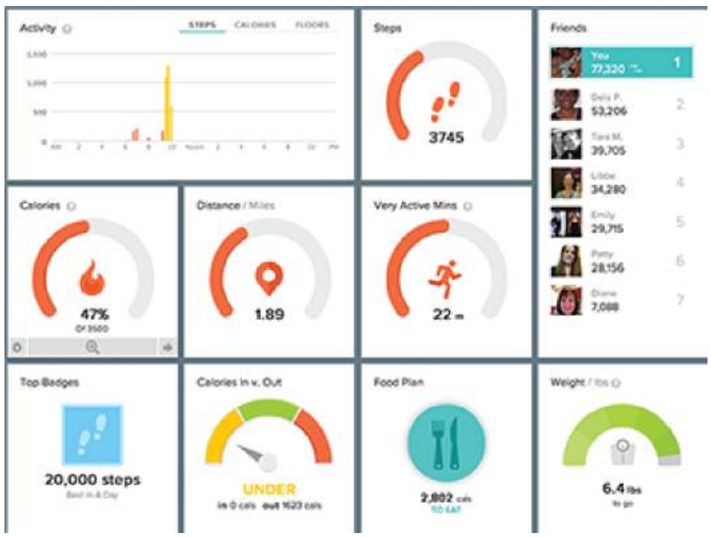

Figure 12 Screenshot of the Fitbit Flex dashboard from the iOS App Store

Like the Jawbone Up, the Fitbit Flex suffers from having to manually input a lot of information for it to be useful. Though it is flawless while tracking your sleep, sleeping with the idea that you are wearing something on your wrist, much like the Jawbone, makes it uncomfortable. The Fitbit Flex also measures your sexual activity to give the user a more accurate analysis of their physical activity during the day. This again must be manually input, and it asks personal questions such as how vigorous the activity was and for how long. It appeared that this was not generally liked by a lot of the users as gathered from online user forums.

Apple Watch

Apple Watch was launched in April 2015 as a smartwatch with a primary purpose of tracking activity and monitoring health of an individual. The device could measure the heart rate, the number of calories burned by an individual during an activity as well measure sleep quality, if worn throughout the night. The watch was expensive with the cheapest variant selling at $400 as compared to the sub $150 price range of the other products discussed above.

Figure 13 An Apple Watch Series 1

Another unique feature of the Apple watch was that it was not only water proof, it was swim proof. The activity tracking in the Apple watch was through an app named ‘Activity’. Apple had separate apps to measure ‘Workout’ and your heartbeat. They did create an environment in which developers could create apps for the Apple watch that could measure or monitor all these activities in one place. Apple does not have an app to measure sleep quality to this day and it must be done so via third party app developers.

It cannot determine the activity the user is performing on its own. There needs to be a manual input from the user’s end as to whether they are walking or running indoors/outdoors, or swimming among other activities. Moreover, even with the apps measuring sleep quality, manual entry was required to start the measurement before going to sleep.

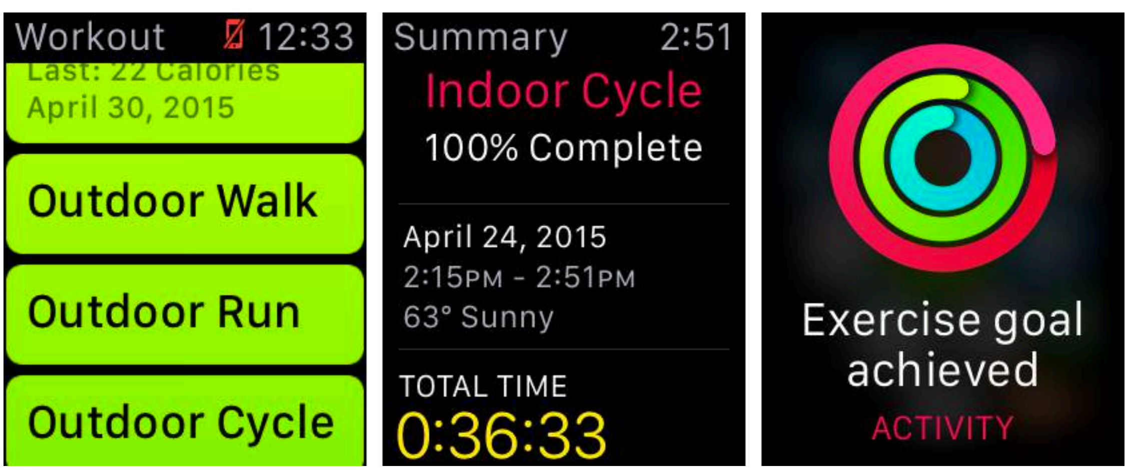

Figure 14 Screenshots of the “Workout’ and “Activity” app of the Apple watch

The battery life was about 8 hours which was not ideal if the user wanted to measure sleep patterns for longer durations than that. The cardiac monitoring part of the watch has improved over time and the latest edition of the Apple Watch measures the resting heart rate, atrial fibrillation and incorporates a GPS. Though used in some cases by doctors to help patients[45], the Apple watch does not integrate with the medical infrastructure.

Based on the usage of the four devices described above, currently, it appears that they are just glorified physical activity trackers. There is not much context based and qualitative health monitoring happening with these wristbands. It is also important to understand that a good amount of time spent at home is not measured or tracked. These devices generate large amounts of data, but it seems to that almost none of it will be useful in a clinical visit.

User Research

The next step in the research was to conduct user interviews to understand their needs from a personalized health monitoring point of view. The aim of the study was to understand the user's thoughts about existing health monitoring systems and determine whether a system can be designed that might be adopted by individuals for everyday use – even by those who would not characterize themselves as sick or in need of health monitoring. The aim was to design and develop a health monitoring system after analyzing the results from these interviews.

10 Rochester based health professionals including a gerontologist, 3 nurses specializing in home care, 3 neuropsychologists and 2 general physicians and a doctor specializing geriatrics, were interviewed. These interviews ended up as unstructured conversations as these experts could not visualize how non-clinical monitoring using emerging technology would help with their practice. The nurses especially had not yet considered the depth of the patient's conditions that technology will be able to monitor. Some of the doctors suggested new health status indicators that could be tracked outside the clinic and these suggestions were researched further. They could be categorized as "reactions to daily activities", for example, when an individual becomes unduly anxious while in traffic or changes in an individual's speed of interaction while using certain appliances in the house.

It became apparent from these early interviews that visual aids were necessary to help explain how emerging technologies can be used for health monitoring to doctors and consumers. It became apparent that most doctors (especially clinicians) and nurses have limited exposure to health monitoring devices outside a clinical setting. Clinicians are used to evaluating patients based on limited clinic data. Everyday users may have used a bathroom scale, thermometer or even a smart wearable device but they need to understand the capabilities of emerging health monitoring technologies. Data displays representing a variety of situations for a hypothetical patient or family to help overcome these barriers, were designed. These were used to drive the interviews and participants were made aware that these data displays were not prototypes but concepts to illustrate the capabilities of long term health monitoring systems. The individuals were asked not to think about how these data displays were obtained but rather reflect on these concepts and provide detailed reactions by envisioning themselves or their patients' health monitoring.

The strategies used to design the data displays are listed below

1. Data should clearly show long term monitoring to suggest that data collected over time can reveal patterns of change.
2. Data should include context which can be used to interpret why the change occurred.
3. Data should highlight the extent of a problem or document progress made to motivate the individual.
4. Data can be organized in ways other than by time.
5. Quantitative data can be used in combination with qualitative data (e.g., journal entries).
6. Data can show comparisons with personal goals, population norms and family members.

10 mock data display examples were developed, covering multiple tracking concepts. These displays were developed, keeping in mind the computing and wearable technology available. The displays were categorized as follows: a) Weight Displays, b) Scenario Displays, c) Body based displays and d) Time based displays. The four categories are described in detail below. Sorting exercises were developed to provide users with a way to express their tracking priorities. This in addition to the feedback provided to the displays would help design and develop the health monitoring system.

Weight Displays

The weight display series was used to create a story with a familiar and commonly accepted clinical metric. The displays start with a static note of the patient's weight at the clinic during a visit and gradually transitions to a richer data display with diverse sources of data added to it. The second display for example adds the patient's weight from one year ago and compares the values with the established norms for gender and height. The second display indicates that though the patient is overweight, the individual has made significant improvement with respect to their goal of weight loss. The third display adds some more data points showing the weight the patient has been recording every month over the year. This is accompanied by the pedometer readings (fourth display) plotted for each month. Participants were also shown photographs taken each month when the patient's weight was recorded and a display of images of the good and bad days of the patient. The good days corresponded to images taken by the patient when they met their exercise goal and bad days correspond to days when they did not meet the goals.

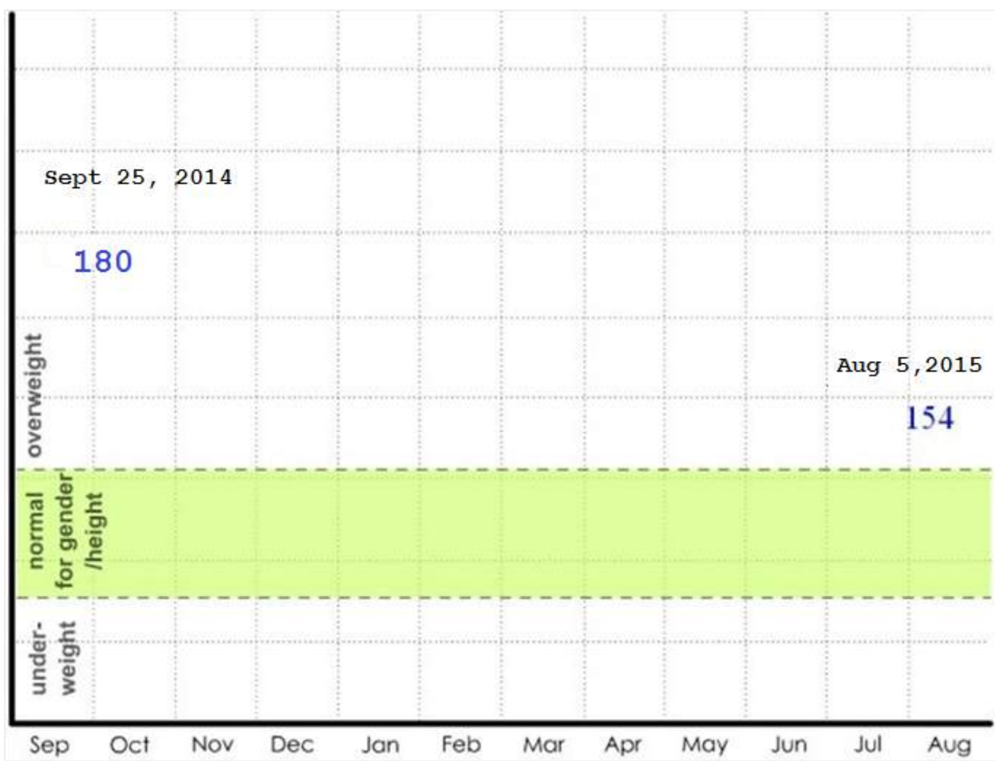

Figure 15 Weight display with the patient's weight from a year ago and the patient's current weight

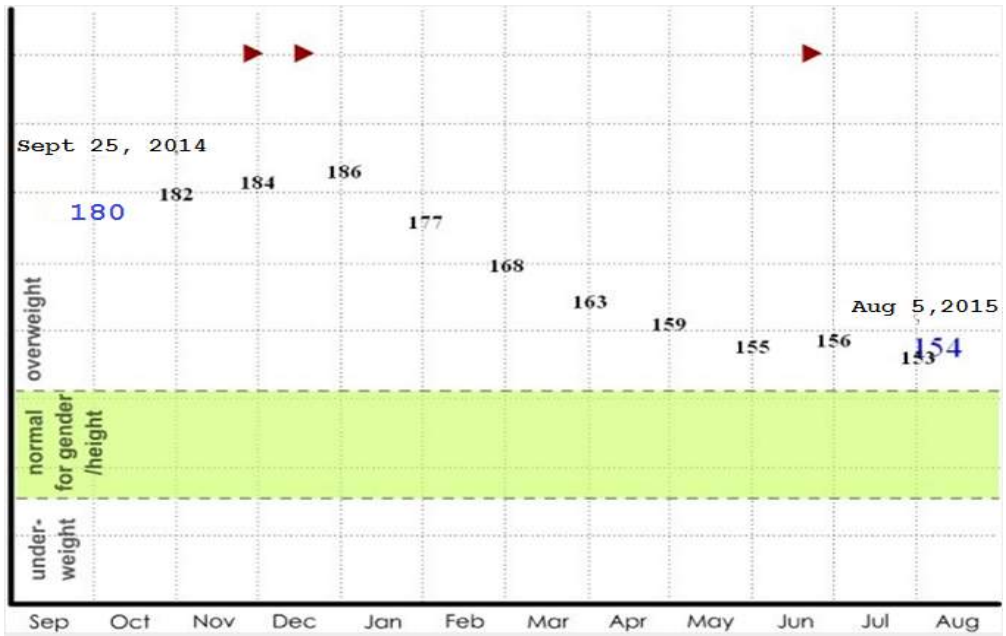

Figure 16 Weight display with the patient's weight as measured by the patient over the course of the year

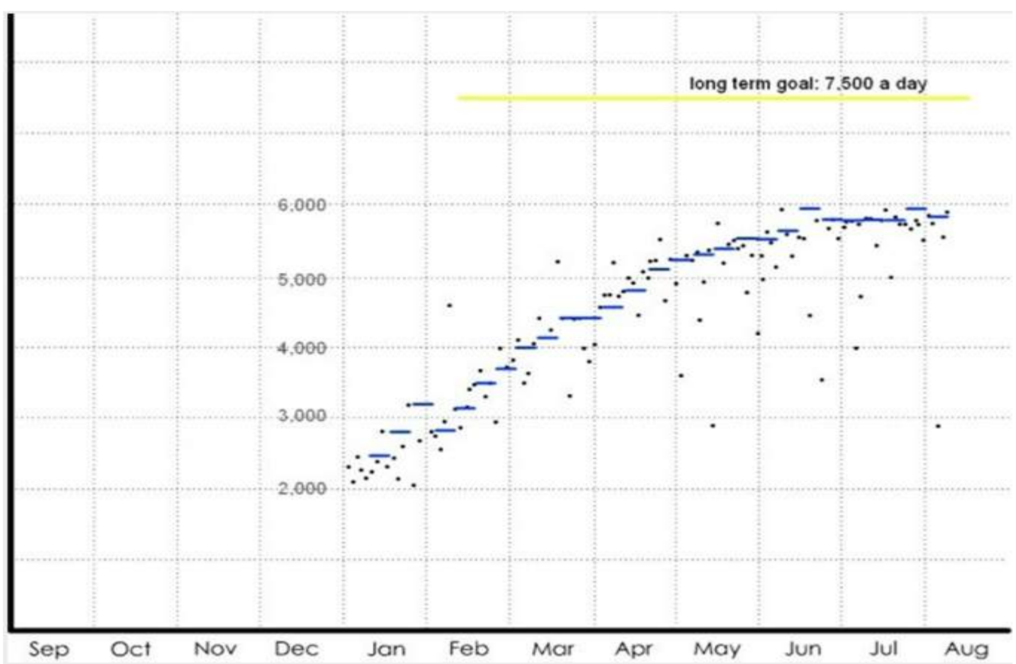

Figure 17 Weight display with the patient's pedometer readings from January through August

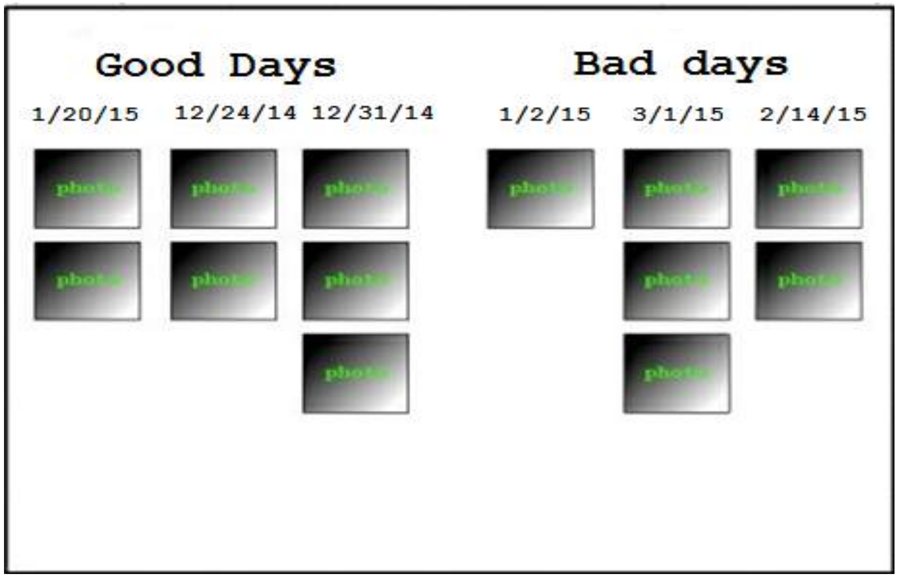

Figure 18 Weights display depicting photographs of the patient's good and bad days during weight loss period

The series depicts a story of a patient struggling with weight loss issues who committed to change, used a pedometer and weight scale to record, and was motivated by the progress. After weight reduction by the patient, the graph reaches a plateau – a point which could drive the patient to slack in their progress. The photographs and the historical data will act as tools to aid the physician-patient conversation in working through the impasse.

Scenario Displays

The scenario displays were developed to specifically provide the participants with a more novel tracking concept. The goal was to develop displays like the media currently used to record and reflect on personal data. The journal display was created with the idea of asking the participants to imagine that they had the time and discipline to create a detailed journal with information on their eating and snacking habits. This focused on subjective recording and analysis of behavior. The health snoop display was created to provide objective observations, developed by the system based on an individual's routine, on the various habits and missed opportunities to work out by the patient. Another display idea was to include data on a grocery receipt. These examples were created to get the participants to focus on reviewing and applying the data rather than on collecting the data.

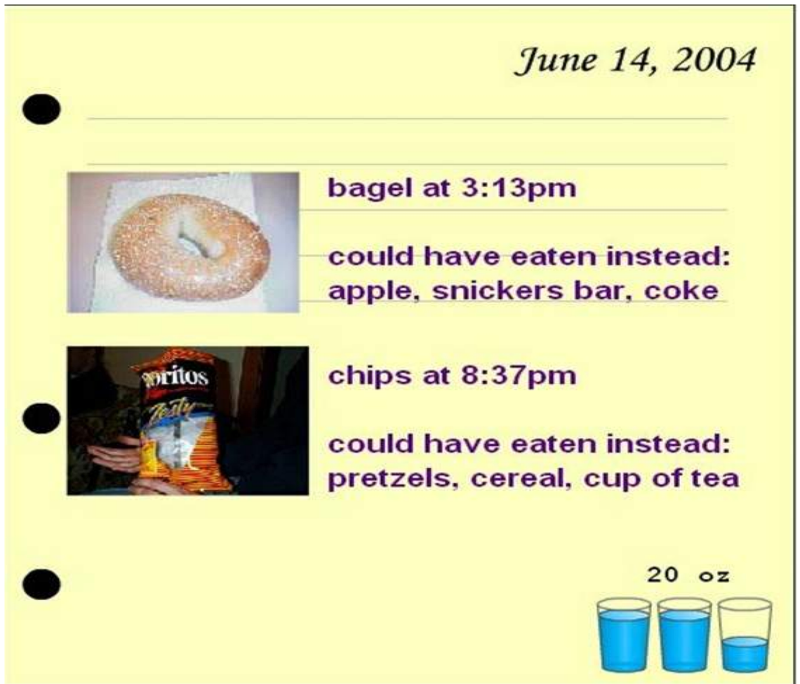

Figure 19 Scenario display depicting journal entry of patient's eating and snacking habits

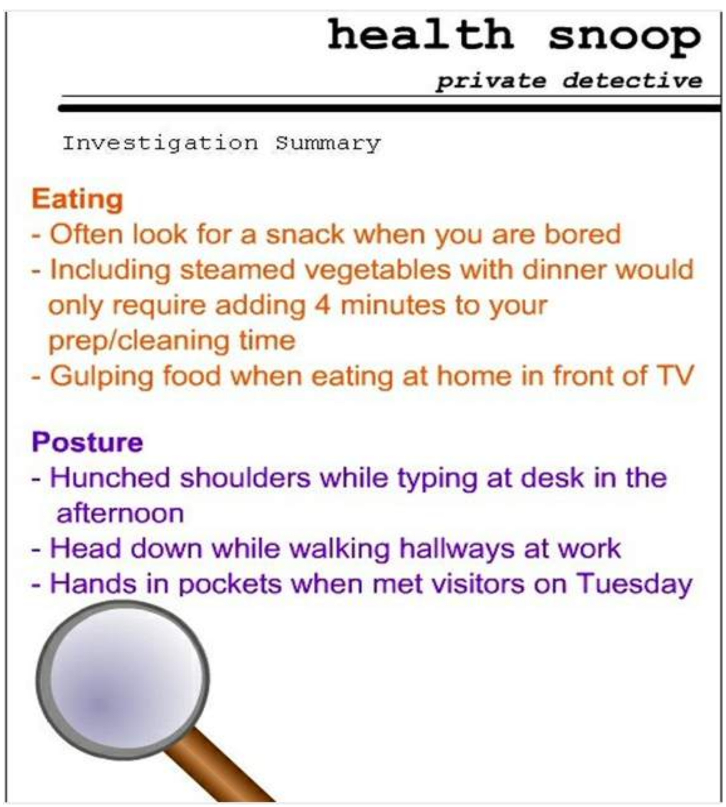

Figure 20 Scenario display showing objective summary of patient's health

Figure 21 Scenario display showing personalized graphical information printed on patient's grocery receipts

Body-Based Displays

The idea behind the body-based displays was to create an example where it was possible to track multiple data points at once. The body example categorized tracked data according to various body regions. The participant could review changes in skin condition, impact of exercise, muscle tone, aches and pains in a region of the body. The goal of this template was to encourage brainstorming, wherein the participant could feel comfortable providing gut reactions to specific ideas displayed. This could lead to a detailed discussion on health tracking.

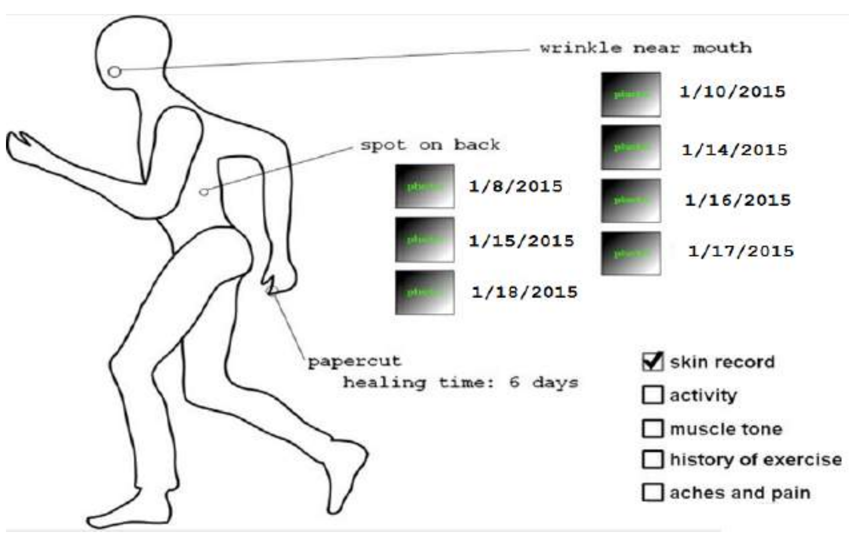

Figure 22 Body-based display showing patient's skin records with photographs

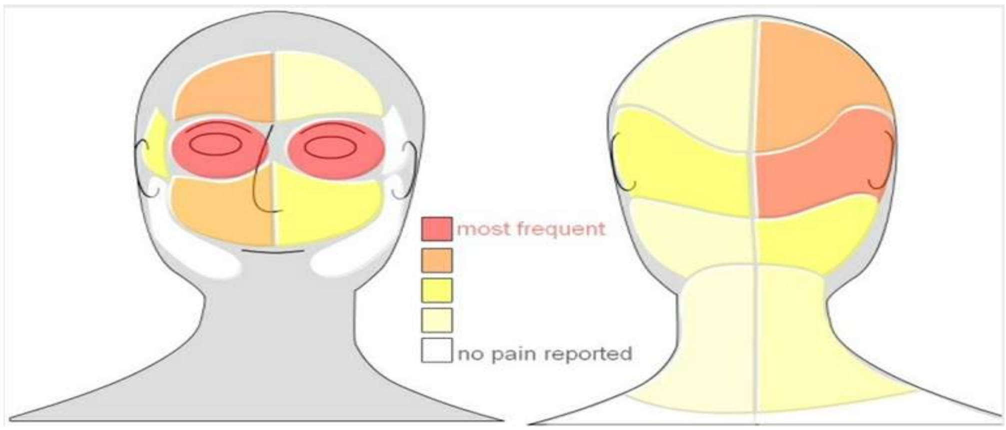

Figure 23 Body-based display showing patient's aches and pain record with intensity

Time Scale Displays

A traditional graph style display was used to show monitoring across multiple time periods (days, weeks or months). The Y axis was not labeled to ensure the participant was not fixated on absolute numbers. The template developed for this was a graph depicting the time spent on idle activities indoor against the time spend on outdoor activities. Metrics of interest such as stress or mood could be analyzed in isolation (e.g., mood during the day) or in relationship to something specific (e.g., mood while watching TV).

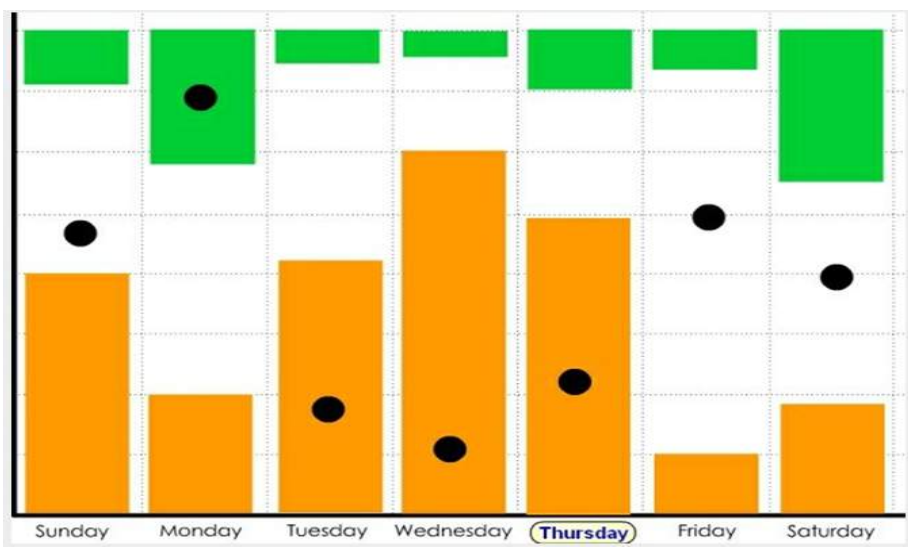

Figure 24 Graph showing time spent by the patient at home (orange), time spent outdoors (green) and mood rating (black dot)

Interview with Health Professionals

Procedure:

Eight health professionals working at Rochester General Hospital, including a home nurse, two geriatric specialists, three general practitioners, and two cardiac specialists were interviewed. These eight were chosen at random from a list provided by the hospital's operations head. The interviews were 45 minutes to an hour in duration and paper-based materials were employed for all the interviews. All the doctors were shown the weight displays, body-based displays and the time scale displays. The participants were instructed to imagine the displayed data was collected using devices in the patient's home and a wearable device. They were also asked to assume that the patient had time to reflect on the data and had prior conversations with a doctor about this.

They were also reminded that the data was not created as a concept and not to reflect the capabilities of current technology. They were asked to comment on how the data might be interpreted by the patient, how helpful the data would be while talking to a patient and what other information would be beneficial. They were encouraged to voice any concerns they might have with regards to the data collection.

Results:

After examining the body display, an interviewee suggested that this could perhaps aid the patient to effectively communicate their concerns to a practitioner. Another interviewee provided a counterpoint wherein he believed that the data would obscure the conversation. He added that he believes that the patient would dwell on the data rather than just say that they have "recurring headaches".

A major point of concern for the doctors was the fear of the patient reacting adversely to the data. For example, providing the patient with information on their stress levels throughout the day is a double-edged sword. The consumer could believe it to be a sign to relax and take a step out of their stress filled life for a while and look at where they stand. But it could also go the other way with the consumer stressing out more and feeling depressed with the amount of stress they are under.

There was also this worry of the consumer or patient not looking at their holistic well-being and instead focusing on one data point. For example, if a person finds himself/herself to be over-weight, then the person would concentrate on just reducing their weight and not take a holistic look at what they are consuming. They might become obsessed with losing weight, which is not ideal. Doctors felt that this could be a point of conversation with the patient if they could intervene in a timely manner, but they felt this would not bode well for the patient.

Overall, they all believed that this long-term data monitoring would be useful to consumers and help them, so they can communicate their concerns to the practitioner more effectively. They believed that this data would help doctors understand behavior patterns that patients might not feel comfortable opening-up about otherwise. For example, displaying in a graph on what was consumed and when, could lead into a discussion about eating disorders. The doctor can then come up with strategies for behavioral change in the patient.

Some of the major benefits the doctors envisioned of the patient coming in with longitudinal health monitoring information are listed below:

- Data collected outside the clinic is likely to be more representative of the patient's actual health. This they believed was the biggest advantage of having this longitudinal data. As mentioned in the example above, the doctors will be able to recognize patterns that will otherwise be unknown as the patients will not look at it as a major point of concern.
- Data can be used to evaluate the success of interventions. They can check on whether their strategy to modify certain behavioral traits was successful. They can also understand the context behind certain behaviors such as eating disorders. They can determine if this was a cyclic occurrence and identify any precursors that led to this behavior.
- Data can also help doctors broach sensitive topics such as the health of their social relationships. They could ask some interesting questions and initiate a healthy dialogue with the patient.
- Data can help patients communicate concerns and can help the doctor make the most of a limited clinical visit.
- Data could be used to motivate and reward progress. Doctors can help patients make progress towards long term goals; recommend some alterations to their life goal assessments. Data can act as contracts for change.

Some of the limitations the doctors envisioned include:

- Family physicians might not have time or willingness to evaluate the data. Physicians who have been treating the family members for a long time will not be interested in the data they are shown. They might believe that they know more about the patients than themselves or what the data might bring to light. With over 50% of doctors in the US over the age of 50, this is a very real possibility unless attitudes change.

- Patients lack the ability to be self-aware about cognitive changes.
- Patients may feel like their privacy or self-image is threatened as data demonstrating decline will be depressing and disempowering. They might make some snap judgements, and this might affect their health drastically.
- Patients might feel like the data does not provide any meaningful life pursuits and the older generation might not continuously use it.
- As mentioned earlier, patients might become obsessed with one data point and take a narrow-minded approach to fixing it than approach their lifestyle and health holistically.

Interview with Consumers

Procedure

20 randomly selected participants were interviewed. 15 of the participants were American, 3 were Indian, 1 Canadian and 1 Mexican. All of them had lived in the United States for at least 5 years at the time of the interview and they volunteered their time without compensation. Participants included 12 men and 8 women, ages 35 to 65 years. Although the target demographic was people in the age group, five individuals in their 20s were also interviewed for comparison. None of the participants were related or affiliated to the author.

The interviews were 30 to 45 minutes in duration. In all interviews, the computer-based data displays were employed. All the participants were shown the scenario, body based and time scale displays. They were reminded that the data was collected in the patient's house and wearable device and that the patient had time to reflect on the data. They were also reminded that the data was not created as a concept and not to reflect the capabilities of current technology.

They were asked to talk about how the data would be useful to them, if they could identify content of interest, how the data might be applied in their daily activities and if they needed more information in addition to the displayed data.

Results:

Overall there was a positive response from the respondents with some of them bringing up some important points. Many of the younger respondents (ages 35-45) were already using a wearable monitoring device. They believed it had a positive impact on their lives, as they were able to make some lifestyle changes such as walking or cycling to a nearby store instead of taking their cars amongst others.

An elderly woman (60 years old) also used a wearable device a year ago but did not anymore. She felt that this tracking device was not ubiquitous enough and found manual data entry for certain functionalities of the device to be tedious.

Many of the respondents believed that they could structure their day with the help of the data obtained from the tracking and ensure that they got the most satisfaction by the end of it. Some of the respondents did not believe that the data being collected was going to be useful to them or the doctors.

One of the correspondents spoke about the demonstration that displayed the mood of a person throughout the day and an infographic that showed the sleep pattern of a person over the period of a month. She believed that these two could be correlated and she could think of how sleep patterns affected her overall mood or how much time she spent with people outside work affected her outlook.

Most of the participants believed that the data should have a social context. They felt that not only seeing how they were doing but also looking at how their friends and family were doing would help in utilizing their device or system a lot more. They believed this could provide a huge motivation and result in long term usage of the device. They also did not like to be monitored at work or while travelling to work.

Another concern voiced on multiple occasions when asked to propose new tracking ideas was concern regarding the obtrusiveness of technology and privacy while being tracked.

Some of the benefits of longitudinal health monitoring as envisioned by the participants include:

- Data will support/supports behavioral change. They could see as to how data would motivate them to change certain lifestyle choices and even enable this transition. They also believed that data when positive would give them a sense of accomplishment.
- Data will help achieve an optimal condition wherein they can go through a day to get

maximum benefit out of it. Understanding how the various interactions affects their mood and stresses them out, they can plan for the same.

- Certain patterns can become evident from the data and help them understand the precursors and influencing factors. This will help them make certain decisions to better their well-being.
- It will help them overcome denial by challenging their beliefs with concrete proof. This could help bring about peace of mind.
- Data will act as a backup memory and influence social interaction.

Some of the limitations of longitudinal health monitoring as envisioned by participants include:

- Actionable information might not be available for every modality that data is collected for. This could lead to buyer's remorse and might lead to social conflict.
- Analytical approach towards data might result in unhealthy reactions and ultimately leave the consumer feeling criticized instead of positively reinforced.
- There is a fear of technology. Though asked not to think about how the data was collected, people fear that the method of collecting data might prove to be too disruptive.
- There is a "not for me" attitude prevalent especially in the age group of 35 to 50 years. They have this preconceived notion that the data and patterns from the data are already known. They feel that this does not apply to them now.
- They believe they might have to work extra hard to ensure the data is accurate. If the data is going to be integrated within the existing medical infrastructure, they want the data that is going to be collected to be accurate.

Sorting Exercises with Consumers

A list of 40 constructs that could be tracked with current or emerging health monitoring technologies was developed. A level of detail to the options, instead of providing a broader, vague domain, such as heart rate instead of cardiac care was provided. These constructs were chosen from a variety of domains such as physical activity (counting steps, distance covered), social interaction (mood rating, idle time) and physiology (blood pressure, heart rate, calories consumed) among others.

Each participant was given 15 mins to answer the questions and could answer if they wanted each construct to be tracked with a "Yes", "No" or "Maybe". They could choose on a printed survey designed by the author.

Results

Most participants were surprised at how many constructs they had selected to track. On average, participants answered "Yes" for 20 of the 40 constructs. While most commonly tracked metrics such as weight, heart rate, blood sugar, blood pressure was chosen by the participants, there were also many metrics such as food (snacking, calories consumed, hydration), mental states (mood, concentration, short term memory) and behaviors (variation from habit, idle time) represented.

Most Frequently Selected Constructs	
N=20	
Construct	**Percentage**
Heart Rate	82
Muscle and Skin tone	76
Correspondence with Family	76
Stress	72
Sleep Quality	72
Short Term Memory	71
Concentration/Focus	71
Aches and Pains	67
Hormone Levels	67
Blood Pressure	62
Blood Sugar	62
Food or Nutrition	60
Variation from Routine	60
Posture	54
Idle time	50

Table 1 Most frequently chosen constructs by participants in the sorting exercise

Technology Research

Importance of Data

The usefulness of smart healthcare devices depends on the quality of information derived from the data collected. Though the doctors might appreciate any sort of data collected outside their clinic setting, to get more insight in to a patient; the issue with healthcare data is that we must monitor health for a long time; maybe months, probably years. A 2009 survey showed that people aged 40-55 years; tend to stop using the device if they find the data irrelevant.[46] The user shall have to perceive the tracked data to be useful for the personalized healthcare systems to be used for extended periods of time. The following example help understand the importance of data in health monitoring.

Data can aid people in improving the environmental conditions that their patients live in, help make lifestyle changes that will reduce the environmental impact on the health of their patients. For example, a team used sensors to track the carbon monoxide emissions in homes in a village in Central Africa. The villagers were educated on the horrific effects of inhaling carbon monoxide and other dangerous gases. Interventions were carried out whenever the sensors showed a spike in the levels of Carbon Monoxide. This study carried over a period of 2 years, helped reduce the fraction of times infants and children below the age of 5 years were diagnosed for Acute Respiratory Infection by 24-64% and for Acute Lower Respiratory Infection by 21-44%.[47]

Data can be considered useful when obtained from products that provide high perceived value to end users. A considerable period is required to understand this value but with people wanting to understand the immediate effects of their health investigations, it is necessary to build a system with technology that would do so.

The importance of context based qualitative data for doctors and consumers alike cannot be overstated, it is important to determine the location to collect data. The most common points of collecting data would be either the user's house, workplace or while commuting to work.

Workplace

The workplace is often associated with tight deadlines, incredible amounts of stress, untimely lunches and long hours. Most of the health monitoring in offices are related to stress, physical injuries or environmental risks.[48] Some of the more recently formed companies in the technology sector, look at human factors and ergonomics. They try to protect their employees from carpel tunnel and vision problems in addition to other stress inducing environmental factors.[49] Google, Microsoft and other tech giants provide food for their employees, so they can avoid junk and fast food. They also provide several amenities such as gymnasiums, spas and other luxuries to help their employees relax. But this is also seen as a method to keep their employees at the office premises and continue working for longer hours. Health monitoring at work has been reduced to a mandatory annual health screening by the employer.[50]

Travel

The average daily commute to work in the US varies between 25 to 75 minutes.[51] There are examples of sensors being embedded in various parts of the car such as the seat belt[52] and steering wheel[53] to monitor stress and other vitals during the commute. Sensors have also been embedded in motorcycle helmets for similar reasons.[54]

Figure 25 Olea car belt sensor unit (left) [52]; 3D printed steering wheel with pressure sensors (right) [53]

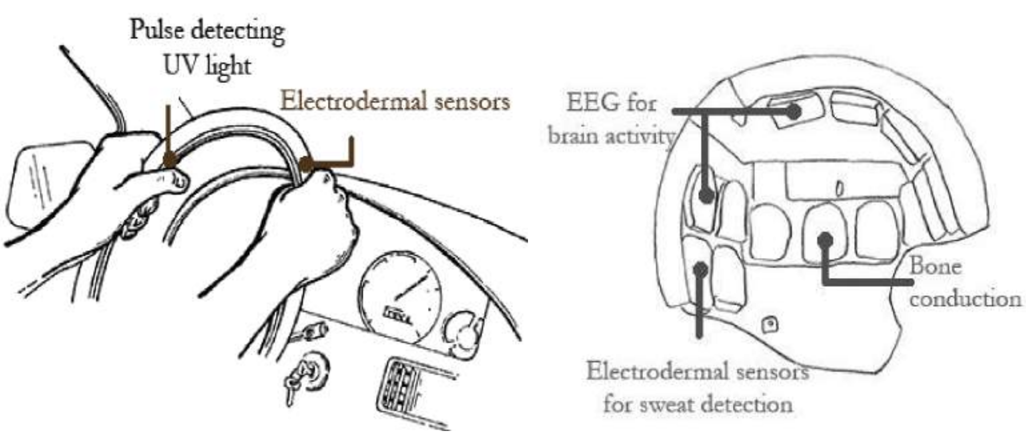

Figure 26 Illustration of sensors placed in car steering wheel (left) [53]; motorcycle helmet (right) to measure vitals[54]

Instead of using multiple devices in multiple locations to measure vitals and stress among other physical and behavioral attributes, a wristband could instead be used for the same. However, a wristband will not help give a complete picture of the user's health.[55] Most users don't use their wearable health monitoring devices once they are home.[55] For effective healthcare, a low cost but high-quality consumer centered health monitoring system at the house of the user should be explicitly supported and encouraged.[55]

Home

There have been many systems and research papers written on home centered long term healthcare monitoring. There are lessons that can be learnt from nearly all of them. A few of them are discussed in detail in this paper.

The earliest smart home healthcare monitoring system experiment was conducted in London in 2005.[56] Three North London homes were retrofitted with medical centers capable of measuring heart rate and blood pressure among other variables. These could be operated by non-medical personnel. Though a good number of variables could be measured, it was not ubiquitous, and it was difficult for the residents to be accurate every single time. They did not feel like making any lifestyle changes, as they did not want to analyze the data. The important benefits included better communication with the practitioners and the practitioners feeling empowered as they could detect any deterioration early in the process. The users felt empowered and were more at ease while talking to the doctors.

The biggest drawbacks of the study also had to do with storing and transmitting the information to the computer servers. Users are not intimidated by technology, but technology must function seamlessly and without any issues for users to continue using them without growing tired. It is also important to understand that 24-hour monitoring is not possible, and it was unnecessary by both the user and practitioner.

The next home healthcare system experiment was called TERVA.[57] TERVA was a wellness monitoring system that was retrofitted in 25 Swedish homes in 2007. It was tested over a period of 10 weeks and it ran off a laptop communicating with several measurement devices in the house that measured heart rate, respiratory rates, weight, body temperature and sleep patterns. Users were also requested to maintain a diary log and to make self-assessments.

The laptop provided a graphical interface for the data collected, showing what range the data fell into. This helped the user gain some context about the data collected, giving them some impetus to analyze the data. Sleep pattern recognition and activity monitoring using motion sensors were the most successful, showing how important unobtrusive health monitoring can be. As expected there were technical issues with devices that needed human intervention.

Matthai Phillipose and his team developed a home-based system known as CARNAC to understand how people picked up habits and how they carried out routine tasks in their daily life.[58] They embedded RFID tags to various devices across the house to understand the user's daily routine tasks. Though it generated a huge amount of data, one had to look closely to discern any identifiable pattern that could be used in the medical clinic. One of the examples, for the doctors was the usage of the bathroom flush. Depending on who used it and how many times it was used, it could help in the early detection of any bowel discomfort. It could also apply for certain specialty cases such as dementia. Though it is better to leave the activities to be monitored to the user so as not to invade their privacy, this system proved the best way to monitor health and well-being would be via a ubiquitous, passive system of sensors.

Health Monitoring Technology

Home

Monitoring, measuring and analyzing user behavior in the homes in addition to ubiquitous measurement of health attributes will help in gaining a deeper understanding of the user's health. Moreover, tolerance to embedded sensors and other technology is high if assessment is set up in the social unit of a family.[57] Acceptance of passive sensors increases if embedded in the environment of daily living.[57] Sleeping patterns, movement, measuring vitals, mood, eating habits are some of the modalities that can be measured and analyzed while in the house. This is more crucial especially for the elderly, who spend a greater portion of their day in the house.

Vitals

A common smart measuring device used in most homes is a smart bathroom scale. The modern scales can measure many metrics in addition to the body mass of an individual. Some of the measures that a weighing scale can provide nowadays include Body Mass index (BMI), body fat, water percentage, muscle and bone mass.[59]

Figure 27 Withings Smart Body Scale[59]

One of the unobtrusive methods for measuring vitals is an Ultra HD Camera with infrared imaging capabilities. This can help measure body temperature without any contact or without using a thermometer. This technique has been found to be accurate to within a tenth of a Fahrenheit.[60] The infrared camera measures the heat dissipated by the various parts of the user's face and categorizes the areas into different gradients depending on how high or low the temperature of the dissipated heat is.

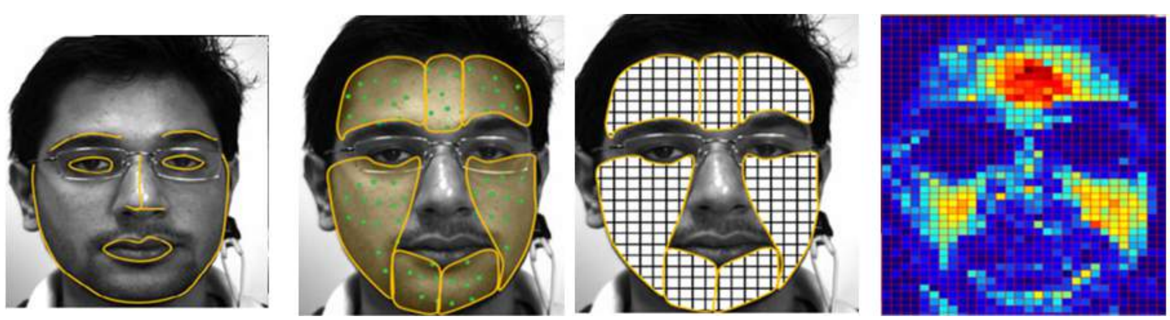

Figure 28 Illustration of the working of a camera-based body temperature system [60]

The Ultra High Definition camera can also measure the pulse of the user. The non-contact measurement of pulse using a camera uses the same principle as that of a finger clip pulse oximeter. The pulse oximeter works by passing two wavelengths of light on to the body which is attached to a photodetector. The wavelength at which the light is absorbed is measured by the photodetector. The light absorption is a result of pulsing arterial blood flow, excluding venous blood flow, skin, fat, tissue, etc.[61] This same principle is extended to measuring the pulse from the blood gushing to the user's face. The photodetector in the UHD camera measures the frequencies at which light is reflected from the user's face or any other region of interest in the user's body with a pulsing arterial blood flow. The component of light (red, blue or green) with the strongest blood volume pulse signal is then computed and the user's heart rate quantified.[62] The accuracy of this technology is found to be within 3 beats per minute.[62]

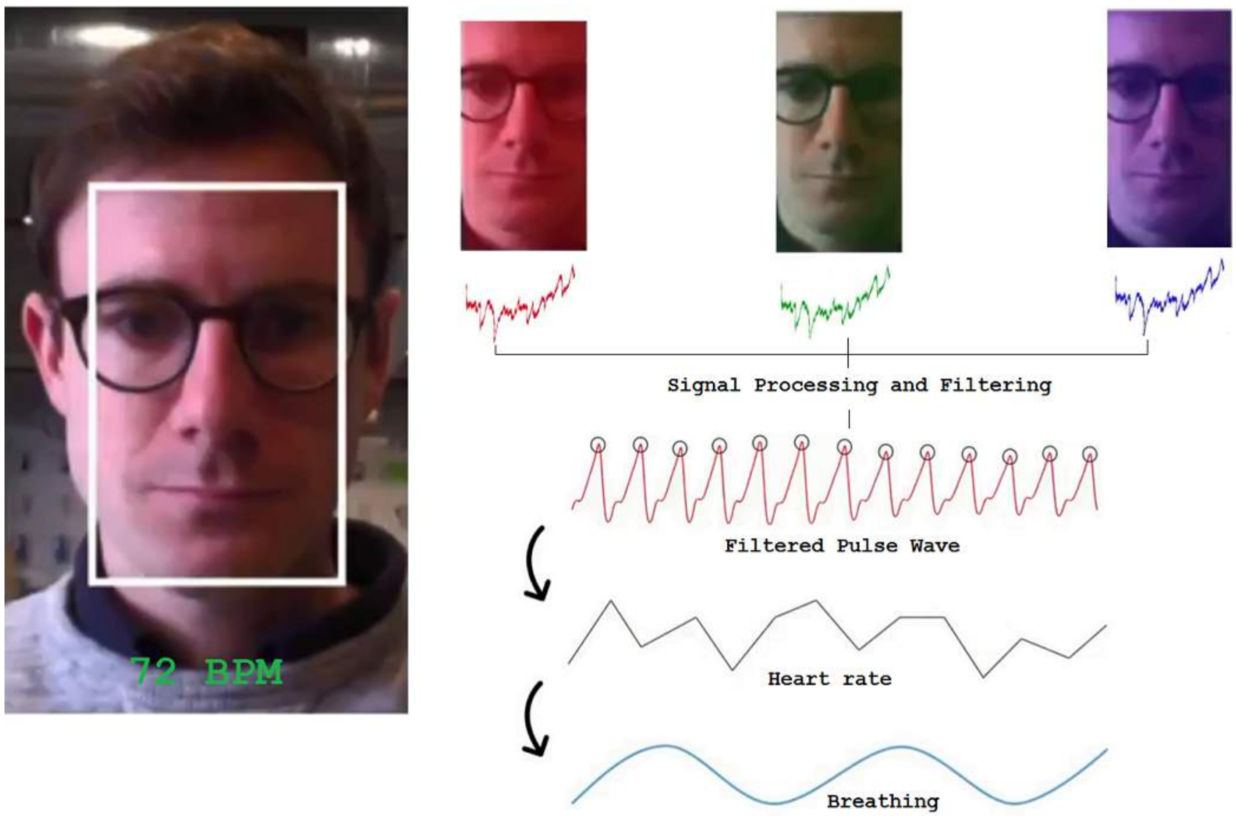

Figure 29 Illustration of the working of camera-based pulse detection system [62]

Another unobtrusive method of measuring body temperature is by using a temporal thermometer.[63] Temporal thermometers use an infrared scanner to measure the temperature of the temporal artery in the forehead. Blood circulating in the temporal artery is pumped from the core of the heart and is considered a good spot to unobtrusively measure body temperature.[64] The temperature can be measured when the person is sleeping.[64] The working principle is like the in-ear thermometers used in several emergency rooms and clinics to measure body temperature.[64]

Figure 30 Illustration showing the working of a temporal Thermometer (left); Withings Temporal Thermometer (right)

Metabolism

In addition to measuring the vitals, a UHD camera can also measure metabolism. Metabolism is a measure of the chemical activity in the body. This can be measured by looking at the time taken by the body to repair itself after an injury or from the tone of skin color. Any changes in skin color tone is measured using a device called reflectance spectrophotometer, which emits light of a specific wavelength and measures the intensity of light reflected by the skin. The wavelength of light emitted by this device is present in regular and LED light bulbs. Thus, by measuring the intensity of the light reflected using the photodetector and by studying skin color changes detected by the UHD camera, we can understand the efficiency of the metabolic activity in the body.[65] For example, the skin tone turning yellow is a sign of liver malfunction, reddening of the skin is the sign of an allergic reaction. The camera can also detect dead skin and any new moles in the body and aid in skin cancer detection.

Understanding the amount of time, it takes for a scar or wound to completely disappear is a sign of how efficient the various chemical processes are in the body.[66] The UHD camera can measure the slightest change in skin tone (color and smoothness). Thus, the camera can track a healing scar or any new scars or pores on the body of the user and then keep track of the changes until it completely disappears. This provides the user with insight on the efficiency of metabolism in their body.[67] The system can also suggest dietary changes working in tandem with the nutrition component of the home-based monitoring system to improve metabolism, thus enabling the user to make necessary changes for the betterment of their health. This feature again will be considering the age of the user, as scars heal at a different rate as people age.[67]

Figure 31 Concept of Samsung Lumini to measure metabolism

The Ultra HD camera set up coupled with a processor or cloud computing will be able to recognize different users using the same device. Once an individual's facial biometrics is stored on the computing device (cloud or physical), it can recognize the individual and tap into their personalized health record. Any health information that is tracked by the system from that point on till another user is recognized will be added to the specific health record. This will be useful when multiple family members share one device at their home to monitor health.

A body mirror combined with advanced imaging technology can unobtrusively track vitals, muscle and skin tone and act as a screen providing personalized health data and visualization. It can also act as a portal for telemedicine. This could be useful for the elderly or the disabled who might not find it easy to go to the doctor.

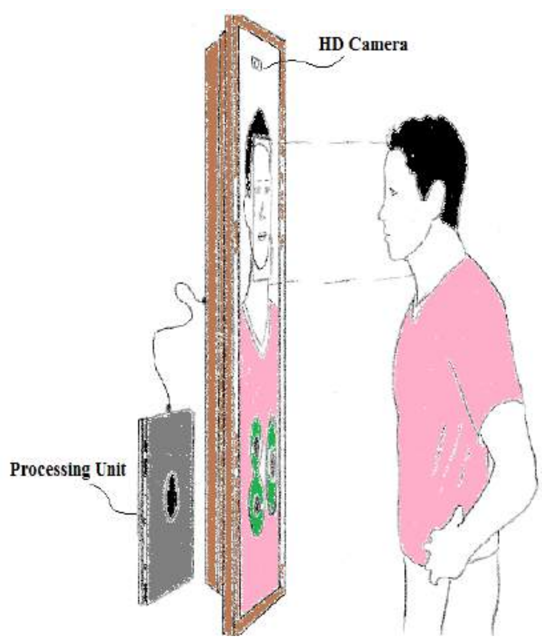

Figure 32 Illustration of a body mirror to measure vitals and other health metrics by the author

Nutrition

Nutrition is of utmost importance while considering the health and well-being of a person. Inconsistency in the duration between meals, consumption of junk food and soda, consuming fat, cholesterol and sugar rich foods leads to belly fat accumulation and other clinical disorders.[68] It is believed that almost 70% of American adults are overweight or obese.[69] Fat content and Cholesterol content are perceived as important information while consuming a particular food item.[70] People judge particular foods to be good or bad, healthy or unhealthy by the food's perceived capacity to affect body weight and its calorie labeling.[71] Calorie labelling is an important public health undertaking to increase awareness of caloric consumption by adding calorie labeling on restaurant menus and food packaging.[72] It was noticed that customers actively considered the calorific value of their foods and it was an important decision making factor.[73]

It is important to watch what one is eating to lead a healthy life. The wristbands and activity trackers that claim to measure calorie intake use an obtrusive method of input. The user must type out the food that he or she ate. They do not list every ingredient and it is a cumbersome process that a user gets tired of easily. 98% of Fitbit flex users do not update food intake information for the wristband to measure calorie counts.[74]

Raman Spectroscopy is a non-destructive and safe technique used in the food safety industry to determine food adulteration at a molecular level.[75] This technique is being widely researched to analyze food components and break them down into various categories such as carbohydrates, lipids, proteins, cholesterol and minerals.[76] Raman spectroscopy has advanced and there are multiple databases that provide the spectroscopic signatures of various proteins, fats, carbohydrates among other food components.[77] Surface enhanced Raman spectroscopy techniques help in detailed classification of lipids into saturated and unsaturated fatty acids, phospholipids and cholesterol among others.[78] At homes, Raman spectrometer can be retrofitted in a microwave or a remote shaped device to unobtrusively measure food calorie intake.

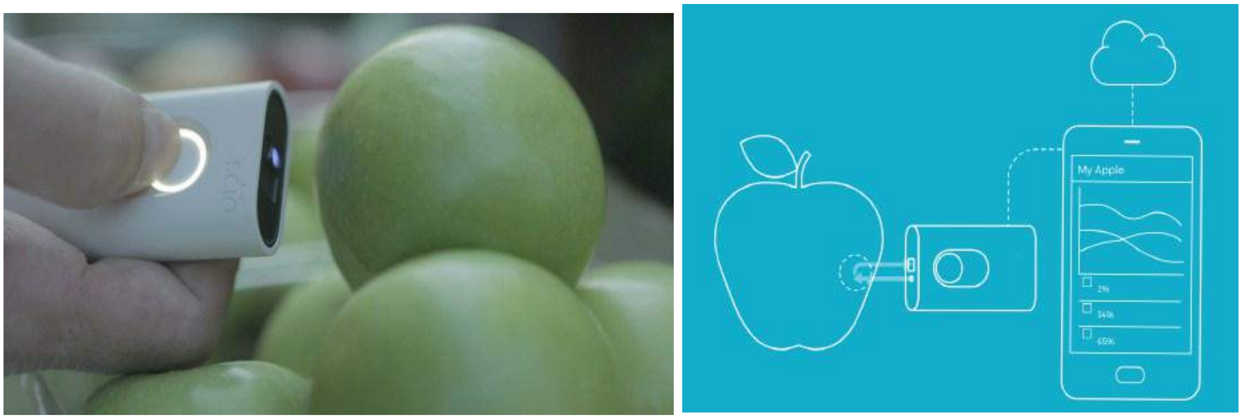

Figure 33 Scia calorie measurement device (left); Illustration of the working of Scia calorie measurement device (right)

Unobtrusive monitoring by hacking simple household objects such as refrigerators, kitchen cabinets and utensils could help in early determination of simple conditions such as eating disorders and even more complex conditions like Parkinson's and Alzheimer's.[79] Motion sensors and Radio Frequency Identification (RFID) tagged every-day objects help recognize variation in patterns while interacting with physical objects and this could help detect conditions early.[80]

Figure 34 Illustration by the author of using RFID tagged kitchen objects to detect health disorders

Sleep

Sleep is an important aspect that must be measured while considering personal health and well-being of a person. Sleep duration can be linked to several clinical conditions such as cardiovascular disease,[81] gastrointestinal disorders[82] and other clinical disorders.[83] Sleep measurement is classified into two components, namely sleep quantity and sleep quality. Sleep quantity is the quantifiable aspect of sleep such as duration of REM sleep, duration of overall sleep, number of times the person woke up in the night and sleep latency among others.[84] This aspect is currently measured by most activity tracking and health monitoring wristbands in the market today, as previously discussed. Another component is sleep quality. This component includes indices such as depth of sleep, how well rested the person feels after getting up and sleep satisfaction.[85] Health care professionals need to concentrate on sleep quantity as well as sleep quality to better understand the correlation between sleep and personal well-being.[86]

One must either wear a wrist band or have sensors under their mattress to measure sleep quality unobtrusively. There are many products on the market today that connect with smartphones and measure sleep.

Figure 35 Beddit 3 Sleep tracking device (left); Metrics measured by Beddit 3 sleep tracking device (right)

Wearables

Vitals

Most smart wearable devices today can measure vitals such as heart rate, blood pressure, respiration rate and pulse rate variability of the user. There are various sensors available that have been miniaturized to fit into a wearable device to measure these metrics. It is important that a wearable device not only measures the heart rate but also measures the resting heart rate of the user and the time taken for the pulse to return to the resting heart rate. It is a great indicator of stress levels and of cardiac health.[87] Elevated resting heart rate is considered a major factor for any cardiac disorder and is a precursor for many cardiac events.[88]

A reduction in resting heart rate over a period is a good reflection on underlying cardiac health and is a good indication that the person has a healthy lifestyle.[89] It is an important prognostic marker for heart disease and total mortality.[90]

Wearable devices can also differentiate between activities such as running, walking, cycling and swimming with the help of accelerometers and gyroscopes fitted in them. Most wearable devices are fitted with a GPS and can map out the user's day which can provide some context into their habits and health. It is also common for wearable devices to have a pedometer to count the number of steps the user has walked in a day and indirectly measure the calorie burned.

Blood Pressure

Pulse Transit time is the time taken for the pulse to travel from the heart to the wrist. This metric can be used to determine the blood pressure of a person without using cuffs or being tied to a machine. Pulse travels faster when the blood pressure is higher and slower when the blood pressure is lower. [91]

The Pulse Transit Time can be used to measure blood pressure when coupled with two sensors, an Electrocardiogram (ECG) sensor and an Optical Heart Rate (PPG) sensor. In a wearable device, the ECG sensor will be located to ensure contact with the wrist and the PPG sensor will be located to ensure contact with the back of the hand. The pulse, which represents a contraction in the heart, will travel down the arm causing a peak wave in the ECG sensor before travelling back up causing a peak wave in the PPG sensor. The time between the peak wave in the ECG and PPG sensors is the Pulse Transit Time and this can be calibrated to give a numerical value akin to the normal blood pressure reading. [92]

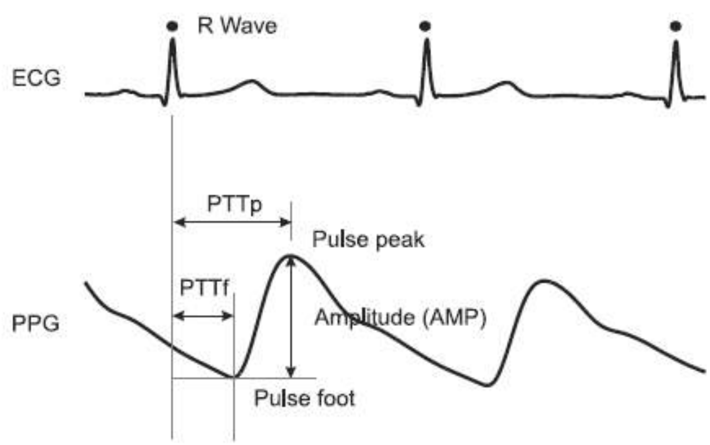

Figure 36 Pulse Transit Time measurement using ECG and PPG Sensor[92]

Nutrition

Nutrition can also be measured without using a Raman spectrometer in a wearable device. Bio impedance sensors can be used to measure food calorie intake and hydration levels of the body.[93]

Bio-impedance is the measure of how well the body impedes current and biomaterials. Fats and proteins have high resistivity and blood cells have low resistivity.[94]

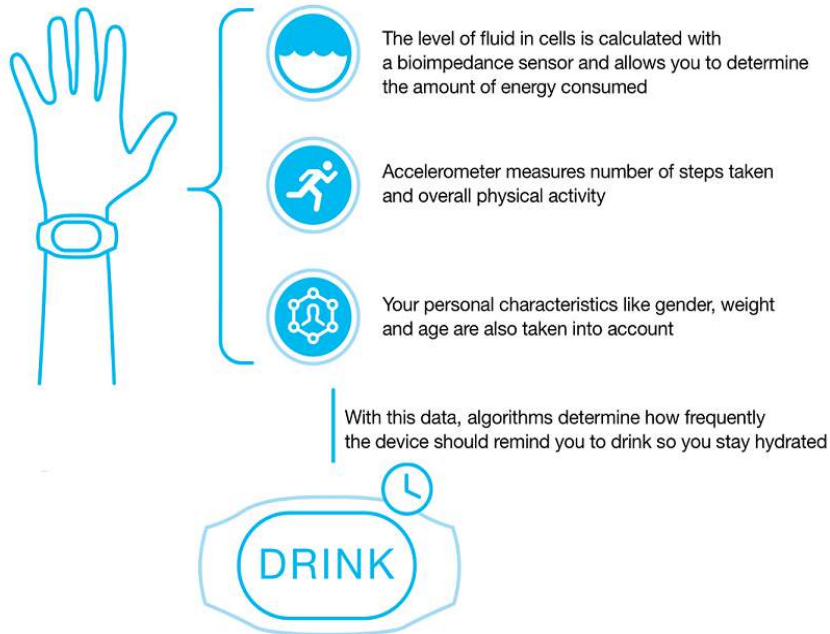

Figure 37 Infographic explaining the working of a bioimpedance sensor measuring body hydration

Tracking of calorie intake using a bio-impedance sensor is determined by measuring the dynamics of a water-glucose mixture that travels throughout the body once digestion of food begins. The sensor sends low and high frequency signals through the skin to determine the liquid movement and thus determining the amount of fats, proteins and carbohydrates consumed by the user. [94] The sensor can also be used to determine the calories burned by the user by coupling it with a piezo sensor, which measures heart rate and blood flow and an accelerometer, which measures physical activity and movement. The sensor establishes the basal metabolic rate and the number of calories burned for maintaining regular body functions as well as the number of calories burned while digestion. The piezo sensor shows how much stress is applied by a user during physical activities and the accelerometer measures the calories burned by any physical activity the user does. The sum gives the number of calories burned by the user in a day. [94]

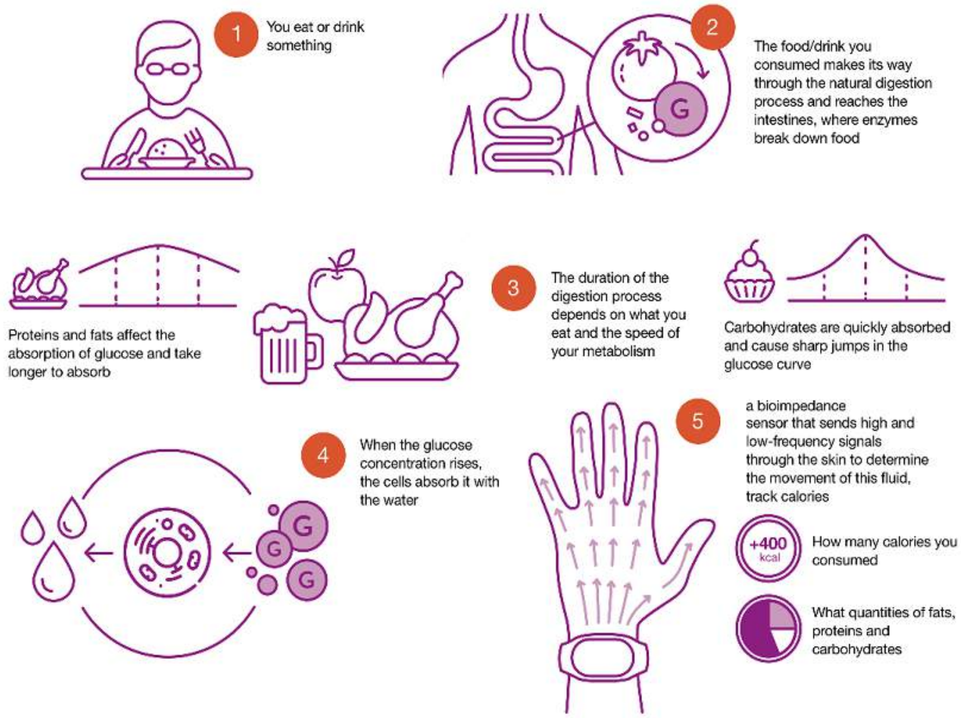

Figure 38 Infographic explaining the working of a bioimpedance sensor measuring calorie intake

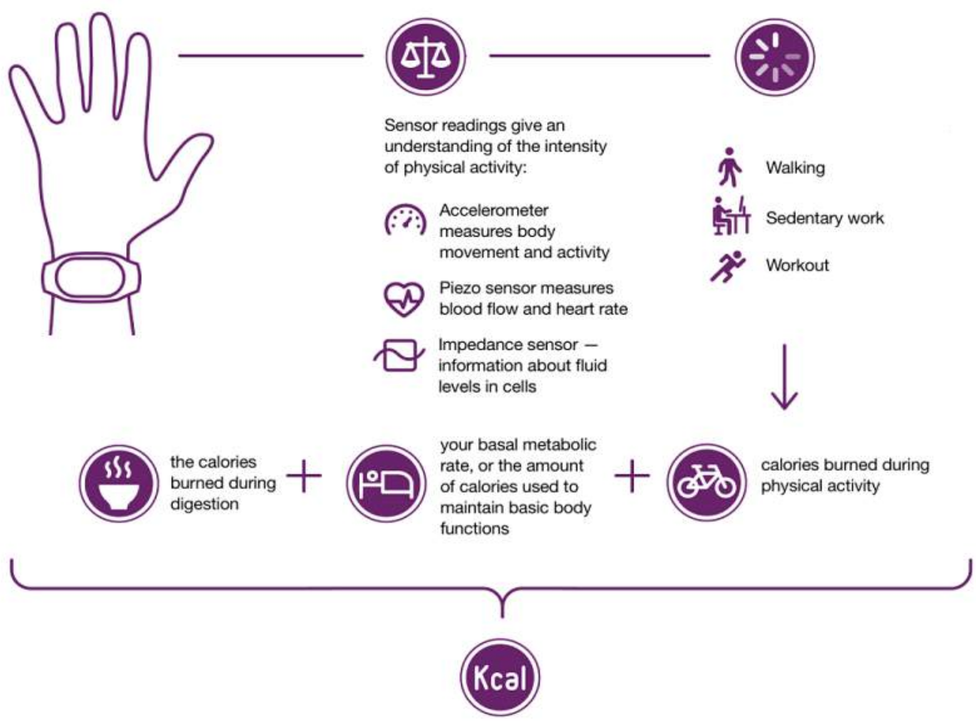

Figure 39 Infographic explaining the working of a bioimpedance sensor measuring calories burned

Smart Glasses

Smart spectacles paired with Augmented Reality helps patients suffering from dementia and other memory loss conditions to help identify their family.[95] These glasses can also track any form of vision degeneration while helping people to go about their life independently.[96]

Figure 40 Illustration of smart glasses (left) and OrCam Smart Glasses (right) [95]

Pill Management

Pill management systems use Radio Frequency Identification (RFID) chips in pill bottles to help remind when a pill must be taken, tracks if the pill was taken and notifies family when the pill is taken. Doctors and nurses can be chosen to be notified as well. The system requires RFID embedded pill bottles and a hub.[97] The problem with such systems is the inability to conclusively tell if the pill was taken by the user.

The US Food and Drug Administration (FDA) recently approved embedding RFID microchip sensors in pills that can monitor certain bodily functions from within the body.[98]

Figure 41 Pill Drill Pill Management System[97]

Integration with medical infrastructure

Figure 42 eMedica Personal Health Record device

The next shift with medical devices would be integration with the medical infrastructure.[99] Currently, the doctor must be an Apple Watch or Fitbit user to utilize the data provided by these devices to help the patient with their ailment. There needs to be better integration with existing medical infrastructure for the users to continue using these devices.[100] In Canada, a startup has created a USB based device which can fit in to your wallet. The health record of the user can be uploaded to this USB device via a computer from the cloud and shared with the user's doctor. This, though not useful in emergency situations and requiring additional steps to upload data, is a step in the right direction in terms of integration of health data with existing medical infrastructure.

Chapter IV – Discussion and Design

Discussion

In the following pages, some impressions, which will be useful while designing health monitoring systems will be summarized. The mock data displays that were developed proved to be a useful method to get participants to provide personal responses to their thoughts on personalized health monitoring and the various concepts presented. The idea was to create a way to help participants to react to the data displays rather than focus on how the technology was implemented. Participants did not have start from scratch with their response. Overall, the data displays were found to be an effective way to elicit several concerns both practitioners and consumers had with health monitoring and help come up with potential metrics for tracking.

The sample size was predominantly American, and the participants were generally aware of existing health monitoring technology. There is a possibility that showing the same data displays to a predominantly non-American population could result in a different set of results.

Participants wanted the ability to use data obtained from heath monitoring devices to conduct short term investigations on themselves. People in their middle life are often dealing with changes to their lifestyle. They are either starting a family, going through a divorce or even considering retirement. They are also trying to address their health issues by working out regularly or via complex dieting practices. Most participants wanted to conduct customized investigations to see how a behavior change is influencing their health or to determine the various factors that are influencing their health and behavior. Most often, these investigations are influenced by a pre-conceived notion that some factors are affecting their health and would like tools to isolate these factors that influence their health. Habitual actions (eating, cooking) or their variation from habits, psychological metrics (mood, work stress, sleep quality) and physical health (weight, heart rate, blood pressure) are some of the common metrics people were interested in investigating.

Participants expressed interest in determining patterns that might not be directly related to health monitoring. For example, participants expressed a desire to investigate their work-life balance and time management. This is possibly a result of the stage of life they are in, but these were not the metrics that came to the mind of the health professionals who were initially interviewed before developing the data displays.

As opposed to the concerns put forth by the health professionals, most participants wanted data even if it was a negative evaluation of their health. They believed that this could promote a behavioral change or help them seek preventive medical help. Another concern put forth by health professionals was allowing their patients to evaluate themselves against the norms. Most participants were ready to evaluate themselves against their own goals and against their family and some close friends. However, they wanted some investigations into their health, e.g., changes in skin tone, to remain private.

Participants wanted control over the communication of data with other people. They did not want to force involvement by sharing data with their family members and friends. Some of them believed that they would not benefit from tracking a metric but other members in their family would. For example, a woman in her 40s believed that tracking the amount of television she watched might not be useful for her, but it would be beneficial to her children. They did not want to be monitored at work or while commuting to work and many privacy issues cropped up. They were interested in comparing their evaluation against a controlled group of family and friends and leveraging this social relationship to address health issues.

Participants felt that data based on short time periods (days to fortnight) were redundant and were not useful to them. Some of them did not grasp the concept of tracking certain metrics over years while some believed that long term tracking would help them to re-assess their life goals. They feel that data is often focused on telling them they are doing something wrong, i.e., reprimand rather than reinforce some positive evaluation. For example, data tells them they are not drinking enough water but does not provide any positive evaluation when they drink enough water. Most participants haven't considered a ubiquitous system that continuously monitors their health, collects data, recognizes patterns and proactively helps them improve their well-being.

Health monitoring and sensing technology have advanced tremendously over the past few years offering impressive new capabilities that can support and enhance traditional clinical health assessment. The benchmarking has shown that wearable fitness trackers are popular and can collect accurate data, but they don't seem to be connected to the existing medical infrastructure. Moreover, the data they seem to provide to the user is rather stale. They do not provide any insights to the user who loses interest in these devices beyond a point.

The interviews have made it clear that people are interested in home and wearable based health monitoring systems but concerns about cost and privacy show that it is more fruitful to develop them as tools that aid with personalized health investigations. There is a great variance in the type of constructs that people would like to track and people's interest in longitudinal health tracking. It is also clear that the constructs they would like to track changes over time depending on their age, stage of life, health status, curiosity and social interactions. It is recommended to design a ubiquitous health monitoring system that adopts itself to user needs and lending itself to personalized health investigations by the user primarily, in addition to medical professionals in some cases. The system would continuously monitor the user, collect data, understand context, identify patterns and variables that impact the physical, emotional and social health of the user.

Problems with traditional health monitoring	**Solutions of ubiquitous and pervasive health monitoring**
1. Delayed assessment: Patients and physicians typically do not request assessment until a problem arises and reaches considerable severity.	Continuously monitor and use data to encourage patients to seek help.
2. Infrequent assessment: Clinicians lack information about functioning and related behaviors between visits.	Continuously monitor to illuminate patterns and daily variability; provide data directly to patients.
3. Lack of ecological validity: Clinicians typically lack reliable information about patients' functioning in environments of daily life.	Acquire contextually sensitive data to highlight environment-behavior connections and specific incidents that may not be reported in clinical visits.
4. Narrow focus of assessment: Patients and clinicians may overlook early symptoms that are not obviously connected.	Implicit sensing to detect subtle changes in daily routine.
5. Avoidance of testing experiences in clinical settings: Clinical assessment can be tiring, intimidating and seem futile.	Embed assessment into services that have other value propositions. Assessment is woven into everyday routines and devices.
6. Lack of time and discipline required for journaling behaviors and symptoms.	Automate and embed data capture into everyday activities; request and deliver information at system-detected opportune moments; ensure technology continuously reinforces its value.

7. Discordance between individuals' holistic, integrated view of health and the constraints of most self-monitoring systems.	Allow people to explore correlations between contextual and behavioral factors.
8. Feedback accessed by caregivers, clinicians and insurers before patient.	Direct feedback to end users not to caregivers, clinicians, or insurers.
9. Difficulty relating to traditional clinical health metrics and language	Present tailored and interactive visualizations at appropriate moments related to personal routines.
10. "Proactive" focus on self-improvement, wellness and quality of life.	Support users' current concerns, presenting trends of interest, even if these trends may not be directly relevant to clinical care.

Table 2 Comparison of Traditional Health Monitoring vs Ubiquitous Health Monitoring

It is recommended to develop a ubiquitous health monitoring system that does the following:

1. Collect information as unobtrusively as possible with little to no interaction from the end user.
2. Learn user behavior, try to understand context and find appropriate times for the user to reflect and review on their customized health investigations.
3. Help the user with short-term health investigations on issues they choose while at the same time developing a deeper, long-term health monitoring that could be helpful to the practitioner.
4. Help users to build upon investigations they are engaged in such as dieting, exercise or training for physical endurance events.
5. Support areas that indirectly affect a user's health such as stress management, work life balance, idle time management among others.
6. Help people focus on accomplishments and positive behaviors.

Design

Introduction

In the following pages, a personalized health monitoring system; its functioning and features will be discussed. The knowledge gained from the user interviews and understanding of current health monitoring technologies will be utilized to design a system that will help aid and abet users in monitoring their health.

Design Statement

Designing and developing a system of devices that would integrate technology, adapt themselves to consumer behavior change and incorporate healthcare provider integration to help an individual to monitor their health holistically and in a personalized manner.

Aevum

Aevum, derived from Latin for eternal life, will be a multi device system primarily gathering user health information from two sources. The first is a health puck which is a home-based monitoring device shaped like a 3-dimensional curved rectangle. The device can monitor and measure several metrics such as heart rate, ECG, skin and muscle tone, food calorie intake, body temperature and oximetry. It can connect to existing health monitoring products such as smart body weight scales and sleep tracking devices via Bluetooth. It also has a Radio Frequency Identification (RFID) chip that will help it to act as a pill management system. The health puck has a camera and a finger print sensor which will act as biometric identifiers. It can identify and differentiate between different users in a household using these identifiers.

A wristband, i.e., the second source of health data, which is a wearable device that has the capability to measure vital health information such as pulse, blood pressure and blood oxygen levels and other information such as stress levels, intensity and location of body pain, user anxiety and mood rating, food calorie intake, hydration levels, calorie burn and activity. The wristband also has Bluetooth modules that will help to connect it to the user's phone. It has GPS for location tracking, which will help provide context to the data.

The data from both sources will be stored in servers in the cloud. Heuristic algorithms will analyze and provide insight to the user via infographics and text notifications on the mobile app or computer. Healthcare integration is a major point of focus for the system. The doctors can access the patient data on their mobile phones and computers. They can connect to the patient's devices via Bluetooth if they are close enough to it. The home-based device can also connect via USB to the doctor's computer. The user can also share the data right from the app to the doctor.

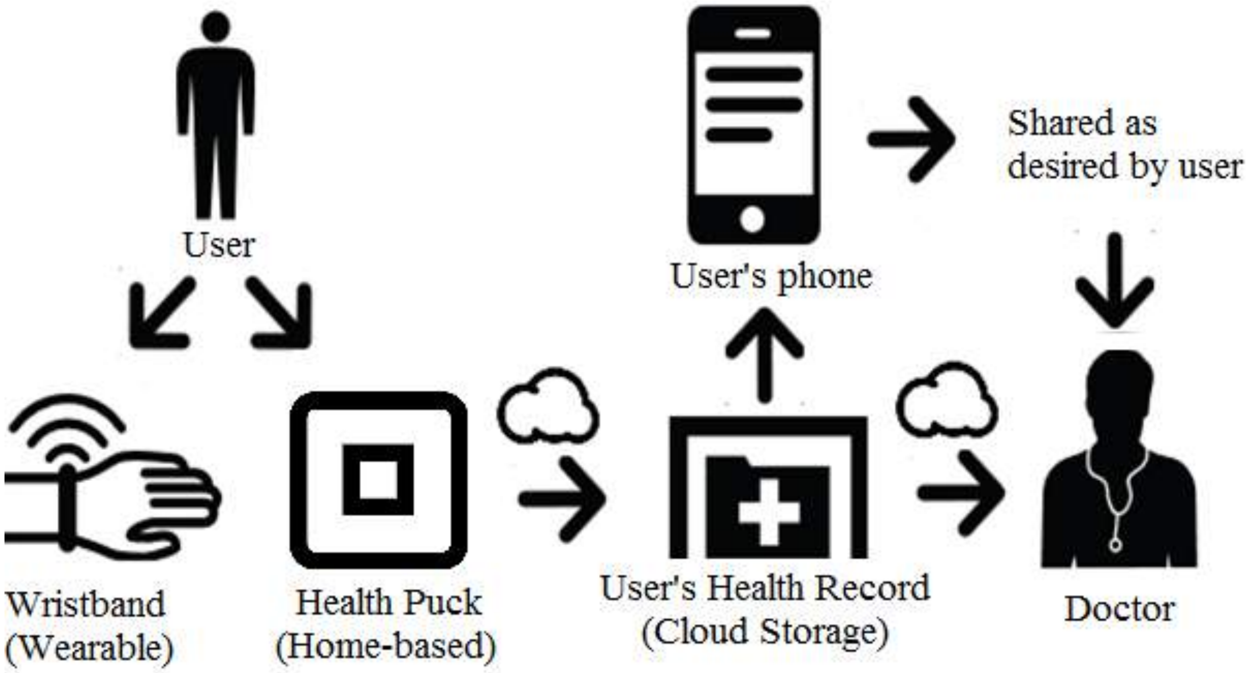

Figure 43 Illustration of the Aevum Health Monitoring System

Health Puck (Home-based device)

The health puck is a 3-dimensional curved rectangular shaped device; the outer cover of which is made of high grade plastic. It has a High definition (HD) 13 Megapixel (MP) camera and a biometric fingerprint scanner. The camera and the fingerprint scanner can help differentiate between users in a household and help provide personalized health monitoring. It also has a processing unit to perform the various functions and transfer data to store in the cloud, a Bluetooth chip to connect to the user's mobile phone and a Wi-Fi chip to connect to the internet. The health puck is designed to be placed on the night stand of the user while also being light and portable. The puck comes with an induction charger. The plastic part of the charger can be detached and mounted on a wall or mirror. The puck can then be attached to this plastic part to access some features. The puck can also be charged via a micro USB charging port which doubles up as a data transfer port.

Figure 44 Aevum health puck front view (left) and perspective view (right)

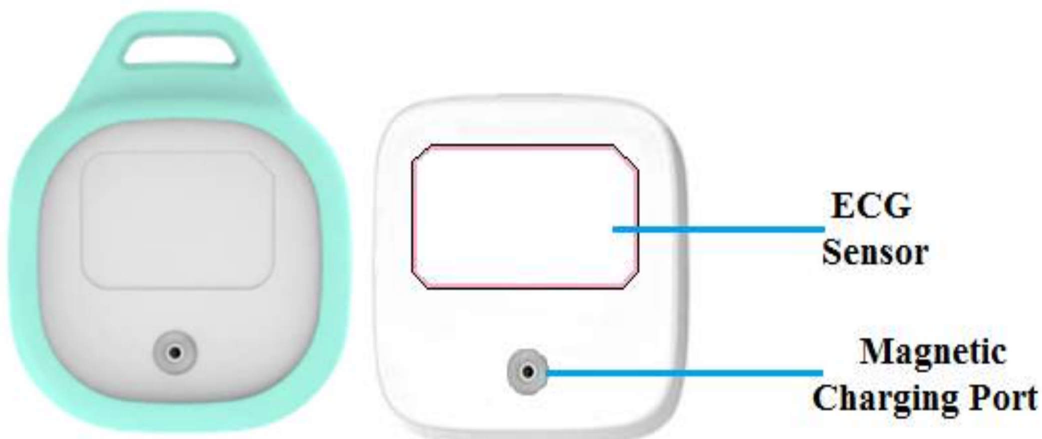

Figure 45 Aevum Health Puck back view (left) and parts (right)

Figure 46 Aevum Health Puck and Wristband induction charger with detachable charging stand

Figure 47 Parts of the Aevum Health Puck

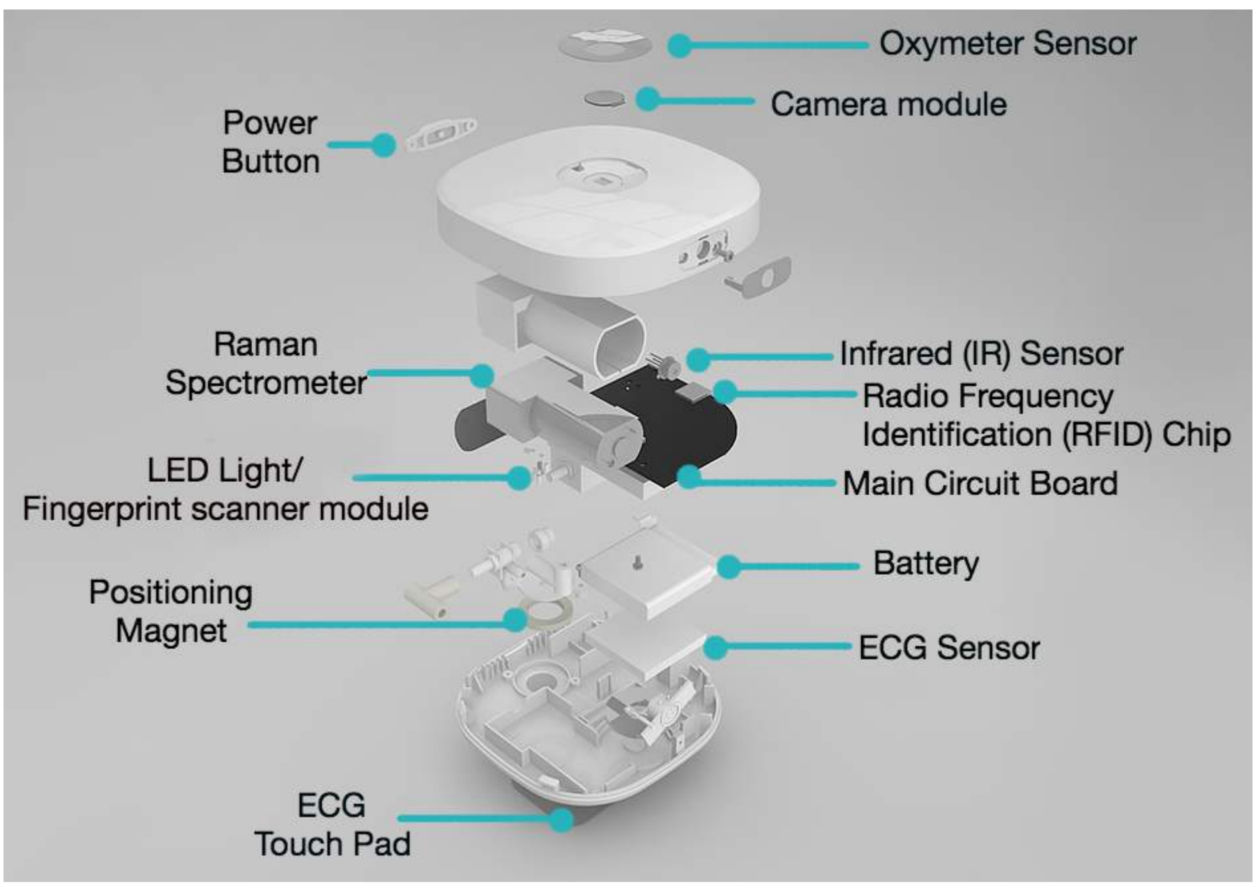

Figure 48 Internal parts of the Aevum Health Puck

The health puck will be able to track and monitor the following health metrics

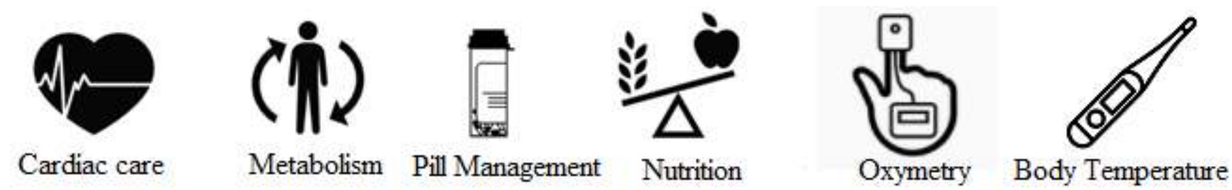

Figure 49 Metrics measured by the Aevum Health Puck

Cardiac Care

The user can measure their pulse rate and Electrocardiogram (ECG) with the help of the health puck. There are multiple ways the user can employ to determine their pulse rate. The first method is like existing finger pulse checking instruments. The user must place their hand over the camera module and press the power button. The pulsing LED light will help determine the user's heart rate.

The other method is to use to point the camera at the user's face. The camera will read the amount of RGB light bouncing off the user's face and determine the user's pulse after filtering and modulating the light signal as described earlier in the research section.

Figure 50 Mounting the Aevum Health Puck on a mirror with charging stand (left) and health puck on charging stand (right) to measure User pulse and mapping user body.

The health puck can also provide Electrocardiogram (ECG) readings of the user. The user must merely place the back of the device on the left-hand side of their chest for 25 – 30 seconds and the ECG sensor will kick in to take care of the rest. It is recommended to wear a light layer of clothing before using this.

Figure 51 Demonstrating ECG measurement with Aevum Health Puck

Metabolism

Aevum will look at muscle tone, skin tone, amount of time it takes for skin lesions to heal and the appearance and disappearance of new moles to determine the metabolic rate of the user. The user must use the plastic part of the charger to hold the health puck against the wall or mirror and stand in front the device. The area of evaluation, determined by the user, will have to be exposed to the puck. The puck will then capture high definition photographs of the user and make a note of any abnormalities in the user's skin. Every time the user uses this feature, the health puck will look at the state of existing skin lesions and look for new lesions. It will maintain a photographic record of every new lesion and look at how long it took for it to heal. Computer vision algorithms will help determine user measurements and create a 3-dimensional body map of the user for this feature. The puck can also measure muscle and fat mass by working in tandem with a smart body weight scale connected to Aevum.

Oximetry

Blood oximetry, which is the oxygen level in the blood is determined in a similar manner as the first method of determining the user's pulse rate. The user places their index finger on top of the oximeter sensor and presses the power button. The LED light pulses and the oximeter sensor determines the blood oxygen levels.

Figure 52 Demonstrating Blood Oximetry measurement on Aevum Health Puck

Body Temperature

The health puck acts as a temporal thermometer to determine the body temperature of the user with the help of the Infrared (IR) sensor. The user holds the puck parallel to their forehead at a close enough distance and the IR sensor picks up the body temperature.

Figure 53 Body Temperature measurement with Aevum Health Puck

Nutrition

The health puck uses a Raman Spectrometer to determine the number of calories consumed by the user in a meal. The spectrometer light hits the food and the detector captures the wavelength that is reflected from the food. Each of the food groups such as carbohydrates and proteins reflect light at a unique wavelength. The intensity of the reflected light will help determine the percentage of a food group in the meal. A combination of the two will help determine the constitution of each meal and in turn the calorie content.

The user must point the face of the puck opposite to the power button towards the food and then press the power button. A red light will be seen on the food and the user must hold down the button till light turns green, signaling the end of the spectrometer reading. It should take around a minute for the spectrometer to complete the process.

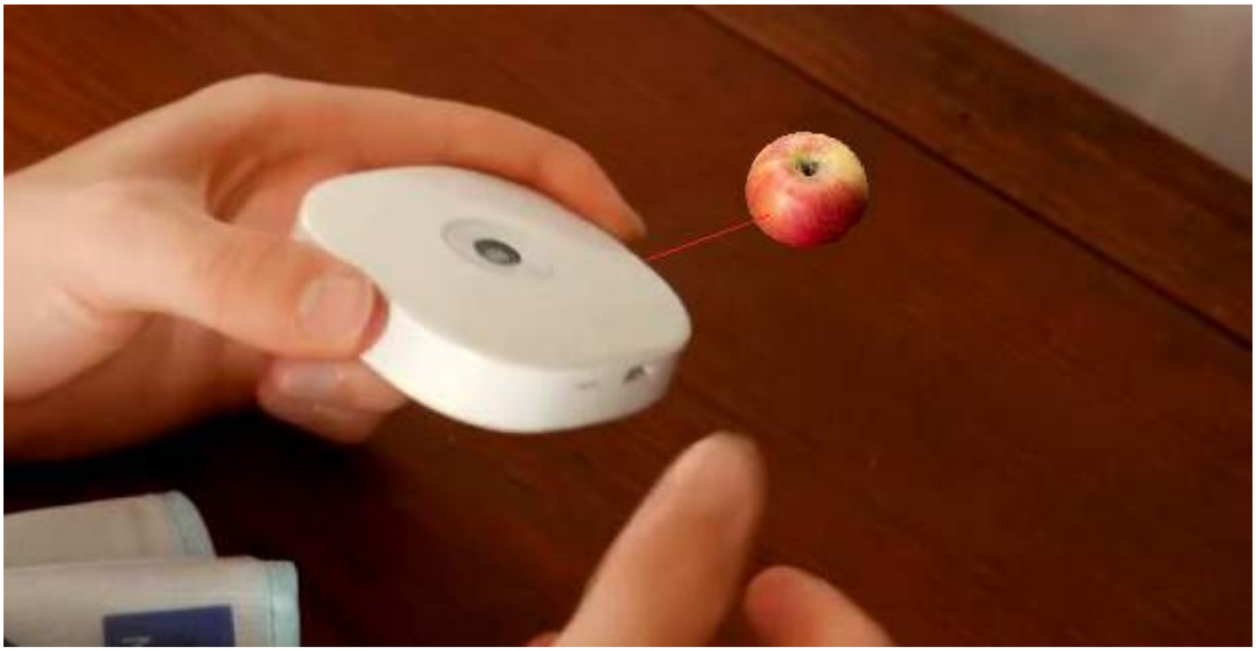

Figure 54 Food calorie measurement using Raman Spectrometer with Aevum Health Puck

Pill Management

The RFID tag present in the circuit board of the health puck will act as a pill management system. The user's prescription will be present in the user's health record maintained by Aevum. The system will know when the user must take a medication and a notification will pop up in the user's phone when it is time to take the medication. The user can then wave the RFID tagged pill bottle by the puck as shown earlier in the research section. The system will then make a note of the time the pill was taken.

Figure 55 Pill Bottle Cap with RFID tag (left) and pill management system using Aevum health puck

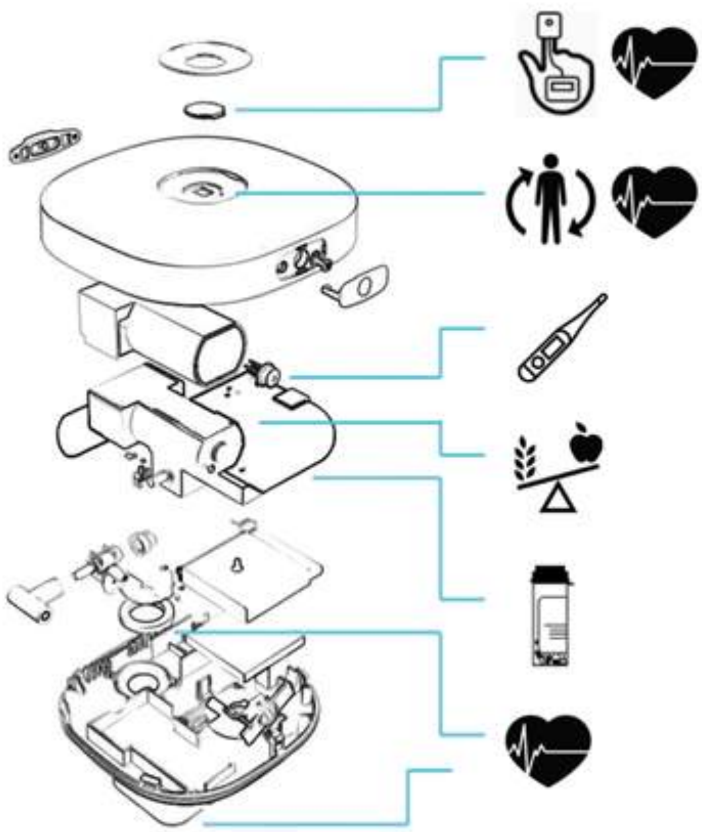

Figure 56 Mapping Metrics measured to Internal parts

Wristband (Wearable device)

The wearable component of Aevum will be an anodized rubber polymer wristband which fits snugly around the user's wrist. The wristband, much like wearable health devices available in the market today, can track vitals such as heart rate (HR sensor; positioned near the wrist), breathing rate and blood oxygen levels (oximeter sensor) in addition to user activity (pedometer, idle time). It can measure the blood pressure of the user without using cuffs or a specialized second device with the Electrocardiogram (ECG) sensor (positioned near the wrist) and optical heart rate (PPG) (positioned at the back of the hand) sensor embedded in it. The device also has a bioimpedance sensor embedded along the inner circumference in the back of the hand close to the heart rate sensor. The bioimpedance sensor will help to calculate the number of calories consumed, calories burned and the hydration level of the user.

Figure 57 3D Printed Aevum wristband

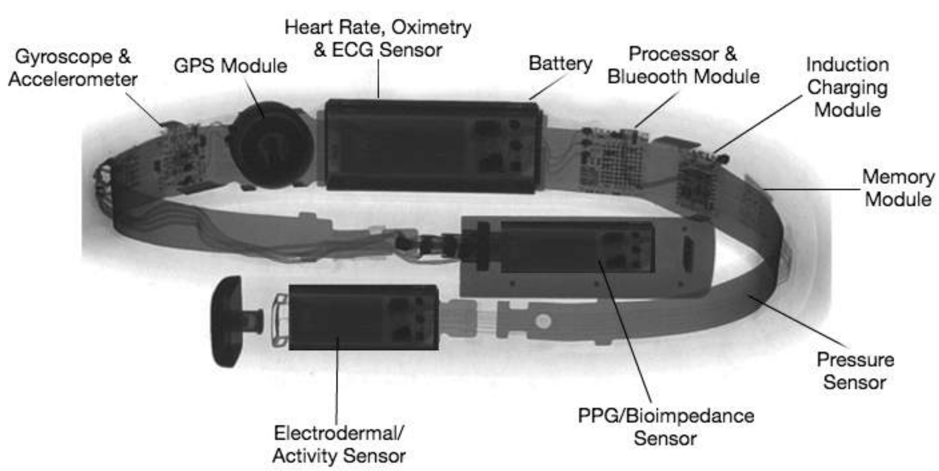

Figure 58 Internal parts of the Aevum wristband

The wristband has an embedded Global Positioning System (GPS) chip that will track the location of the user. This will help provide contextual awareness when analyzing mood or user anxiety by working in tandem with the heart rate and pressure sensors. Pressure sensors are placed along the inner circumference of the device calibrated to determine even the slightest twitch in the user's forearm muscles. The wrist band will also be charged by the induction charger that charges the health puck.

The wristband will help to track and monitor the following health metrics:

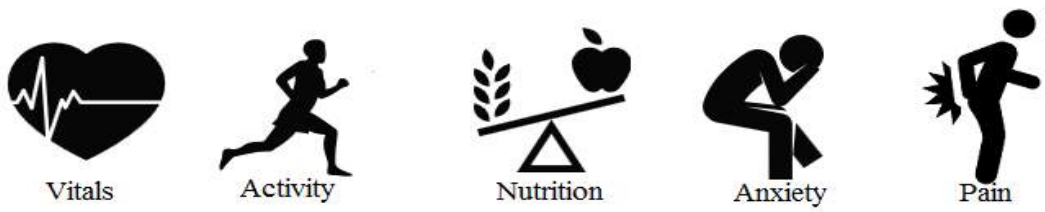

Figure 59 Metrics measured by Aevum wristband

Vitals and Activity

The Aevum wristband will measure vitals such as heart rate, respiration rate and pulse rate variability of the user. The sensors for these will be placed along the inner circumference of the band near the wrist. Additionally, the Aevum wristband will also measure the resting heart rate of the user and the time taken for the pulse to return to the resting heart rate.

Figure 60 Heart rate measurement shown on a Aevum wristband

The wristband measures several activities such as running, walking and swimming. It can determine if a user is walking, running or commuting by combining the data from the Global Positioning System (GPS) and the heart rate sensor. The system can notify the user on their phone to stand up, move around or engage in some physical activity if the wristband notices an extended period of user inactivity.

Figure 61 User activity shown on an Aevum wristband

The Electrocardiogram (ECG) sensor embedded in the wristband near the wrist and the Optical Heart Rate (PPG) sensor embedded along the back of the hand will help to determine the blood pressure based on the pulse transit time. The working of these sensors and blood pressure is calculated from them was explained in the research section.

Figure 62 Blood Pressure measurement shown on an Aevum wristband

Nutrition

The wristband has a bioimpedance sensor embedded on the back of the hand which helps to determine the number of calories consumed, burned and the hydration level of the user. The system can notify the user to drink water if the wristband finds the user's fluid level is low.

Physical Pain

Muscular discomfort reflects tiredness and fatigue in the body. Measuring any physical discomfort unobtrusively could tell the doctors a lot about sleep quality and general fatigue. This is achieved by the wristband by using pressure sensors embedded along the inner circumference of the band. The wristband is tightly snug around the forearm muscles of the user. Thus, when a person uses the forearm muscles to massage, the output is quantified to reflect the intensity of the pain experienced by the user.

Moreover, the device can identify the location of pain. While setting up the health puck at home, the user is also asked to calibrate the wristband. Using the UHD camera and the gyroscopes present in the wristband's circuit, the user's body is mapped by the system. The user will be asked to touch certain points for the system to understand and draw out an accurate body map of the user. So, when the user experiences some pain and instinctively massages the area of discomfort, the wristband will be able to measure the intensity of the pain and the location of the pain. This will be available to the doctor when they access the personalized health record of the user as a 3D model. The pain levels will be color coded. The system's software can provide the user with qualitative information as and when it gathers sufficient data. For example, "Hey Joe keep the exercises going, your back pains have reduced since you started running two weeks ago."

Figure 63 Pressure sensors measuring intensity of forearm muscle movement (insert) on an Aevum wristband

Anxiety and Stress

Stress has been studied by the medical community for decades now to measure its impact on the physical and mental health of a person. Stressors such as negative news, pressure to perform at work under constraints, traumas among others have known to have a damaging impact on the physical and mental health of individuals. Aevum helps individuals understand the causes of anxiety and stress in their life.

It does so by constantly learning about the user's actions and continuously adapting to any behavioral change. Constant elevated heart rate from the resting heart rate is a great indication of any environmental stress. Heartrate sensor activity combined with constant pressure sensor activity can point to any stressors affecting the user at a point in time. Combining all this with location history via the GPS present in the wristband can give the user context about the various stressors in their day to day life and help manage their anxiety better.

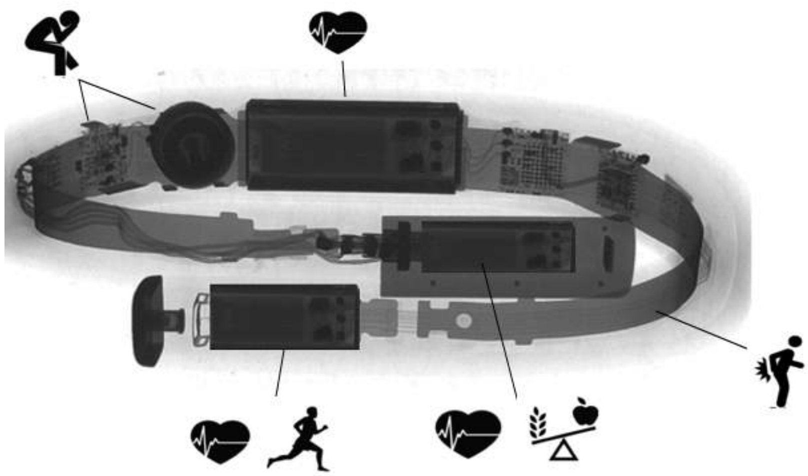

Figure 64 Mapping Metrics to Internal Parts

App Ecosystem

The mobile application helps the user to understand the data with the help of visualizations and notifications. The user can also share information with family members and doctors via the app. Connecting to products beyond the Aevum ecosystem such as body weight scales and sleep monitoring devices is also done via the app.

Figure 65 Aevum App Icon

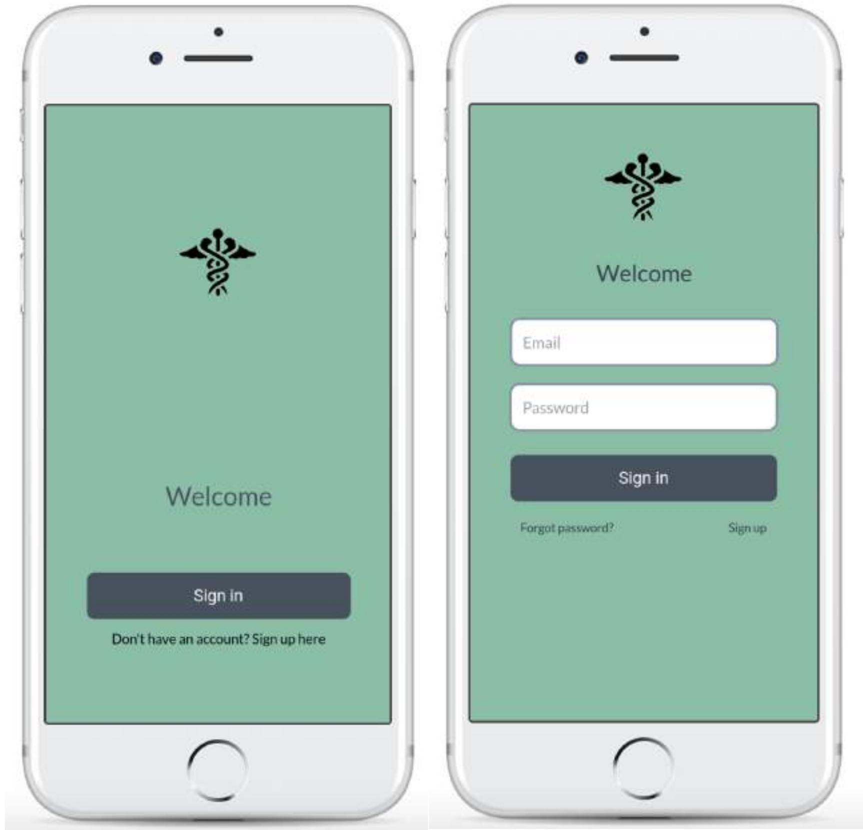

Figure 66 Aevum App welcome (left) and sign-in page (right)

The welcome page is simple with the ability to sign in to Aevum or sign up for new users. Upon signing in, the user is taken to the qualitative dashboard where they can see personalized qualitative output. The system analyzes and compares the user's data with a peer group before providing this output. In the following screenshot, the user is shown analysis about his cardiac health, the effect of exercise on his back pain, positive reinforcement about his activity and a personalized reminder to take his allergy medication because the pollen count is high. The user can press the flip icon on the left-hand side near the Aevum app icon to move to the quantitative dashboard.

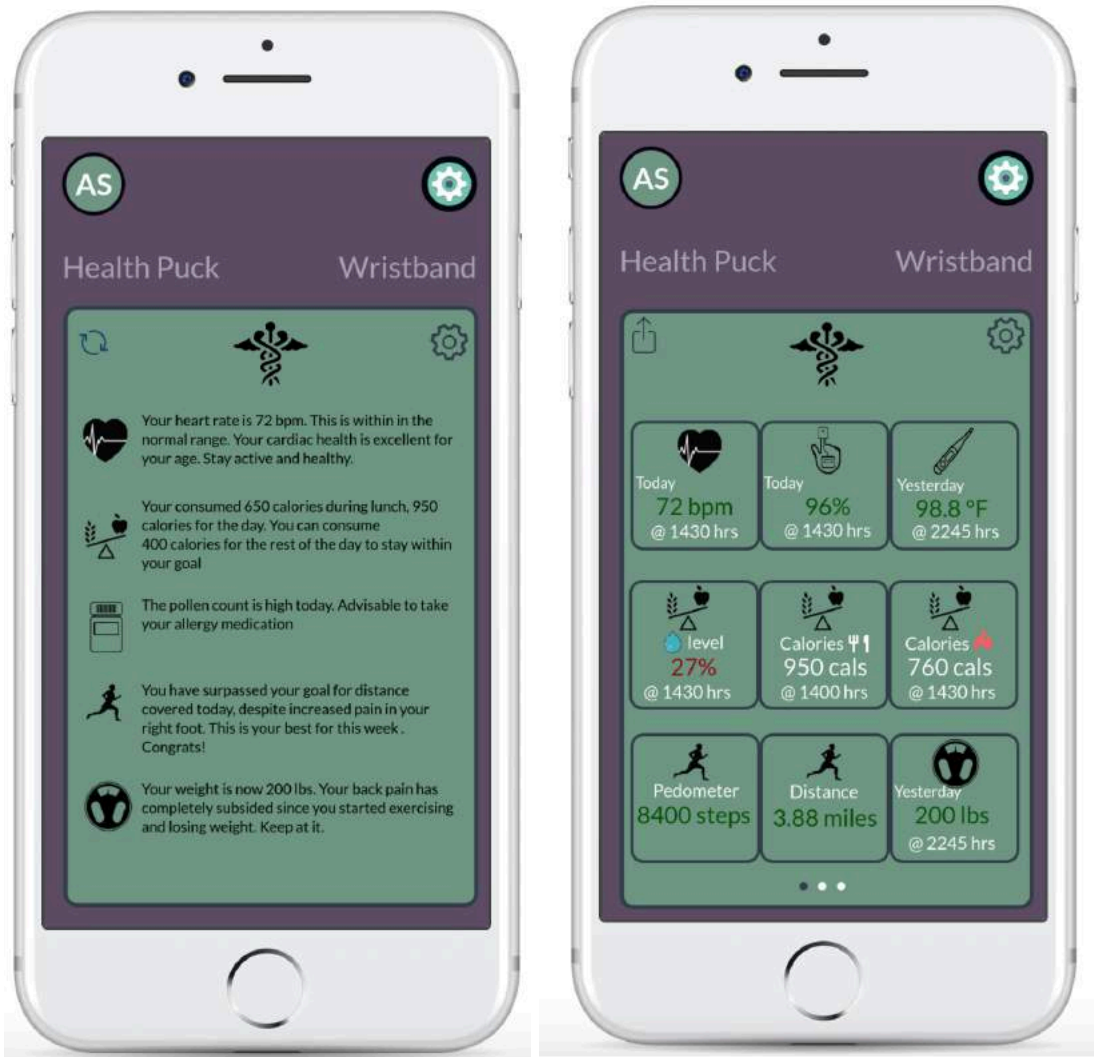

Figure 67 Aevum app Qualitative (left) and Quantitative (right) dashboard

Here the user can see a quick snapshot of the metrics measured by Aevum and other devices that are connected to their profile. They can modify the placement of metrics, add or remove certain metrics by accessing the settings menu (the icon on the right-hand side of the Aevum app icon). The dashboard can be shared by pressing the share icon on the left-hand side of the Aevum app icon. User profile can be accessed by clicking the profile icon on the top left of the screen and Aevum settings icon on the top right of the screen.

-

Figure 68 User Profile Page (left) and Health Record page (right)

The user profile gives some extra information about the user and information on whom the user can share their data with. The orange profiles belong to the doctors the user is associated with and the green profiles are other regular users. The user can also access their health records from their profile. The health records are sourced from the various doctors the user visits. They can add a new source if it is not picked up by the system. The health records page has information on the allergies, clinical vitals, conditions, immunizations, lab results, medications and procedures obtained from the clinics.

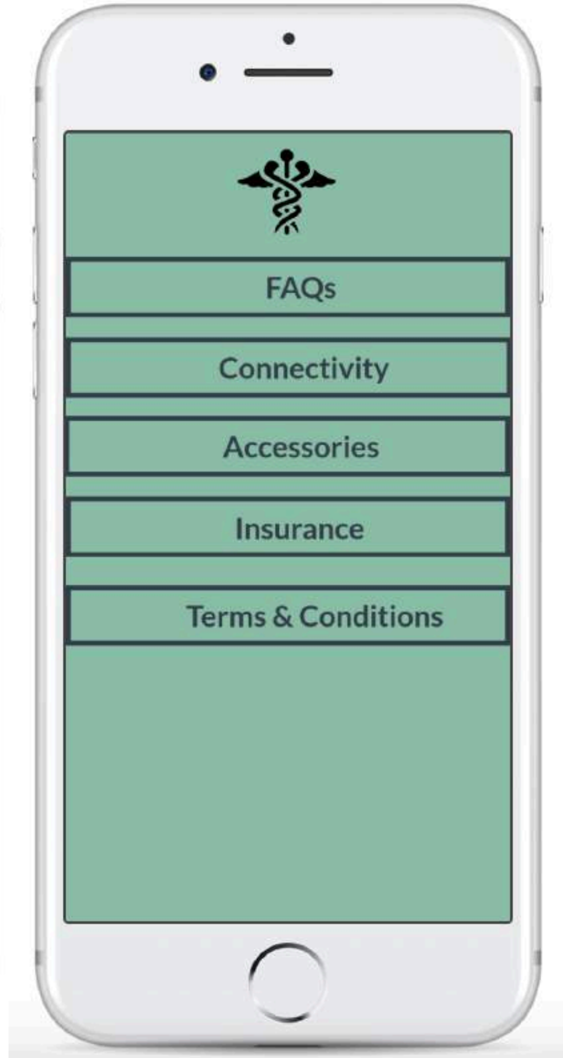

Figure 69 All Records page (left) and Settings Menu (right)

The settings menu has 5 options;

- ***FAQs or Frequently Asked Questions*** which helps the user to understand Aevum better
- ***Connectivity*** shows the connection settings to the health puck, wristband and other devices that share data with the Aevum ecosystem. The user has the capability to add or remove metrics that are measured by Aevum
- ***Accessories*** helps to identify and connect to devices that share data with the Aevum ecosystem
- ***Insurance*** gives more information on the user's insurance plan, gives the user the ability to search for doctors that accept the user's insurance and book appointments.

- ***Terms and Conditions*** explains the various terms and conditions associated with using the Aevum ecosystem

Figure 70 Connectivity Page (left) and Accessories page (right)

The user can return to the main dashboard by clicking the Aevum icon at any point. The dashboard metrics are associated with the metric measured by health puck or the wristband. The user can click the icon to get detailed information about the metric. The user can also choose either the ‘Health Puck’ or ‘Wristband’ options on top of the dashboard to get more information about the metrics measured by a device.

Health Puck

Cardiac care is the home page that pops up when ‘Health Puck’ is chosen from the dashboard. The user can choose the period for the data they want. They can see the last measured heart rate, their maximum and minimum heart rate for the time range chosen, their cardiac fitness and measured life expectancy.

Figure 71 Health Puck cardiac care metric page

They also can see their latest ECG reading on this page. They can click the measure icon to take a new ECG reading or the cardiac care icon to measure their heart rate. The Aevum icon on the bottom left takes them to the dashboard. The rest of the metrics measured by the health puck are on a horizontal carousel in the app and can be accessed by swiping left or right from the cardiac care page.

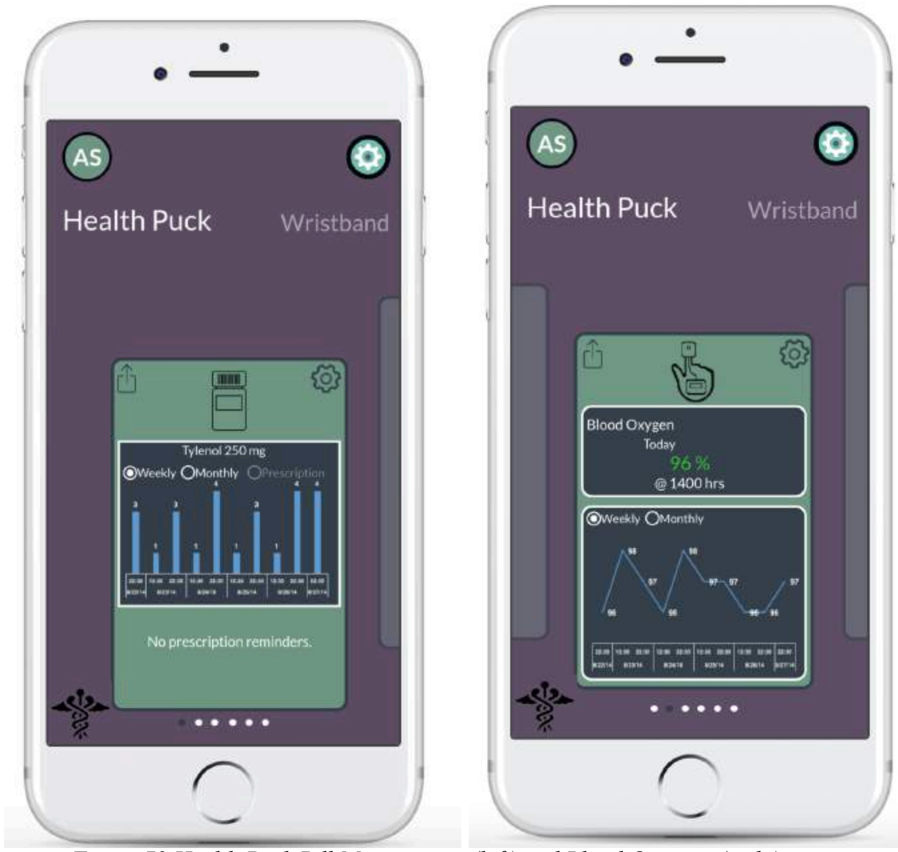

Figure 72 Health Puck Pill Management (left) and Blood Oximetry(right) page

The Oximetry page shows the last measured Blood oxygen levels and a graph to show the weekly and monthly blood oxygen levels. The pill management section is arranged by pills. The graph shows how many pills were taken by the user, every time they consumed one. If the pill was prescribed by a doctor, then the app will automatically notify the user before the pill is to be taken and update the graph after the pill is taken with the time it was taken and number of pills. The user can add non-prescribed pills by clicking the pill management icon and capturing the pill's barcode with the camera. Aevum will automatically recognize the pill and add a new section.

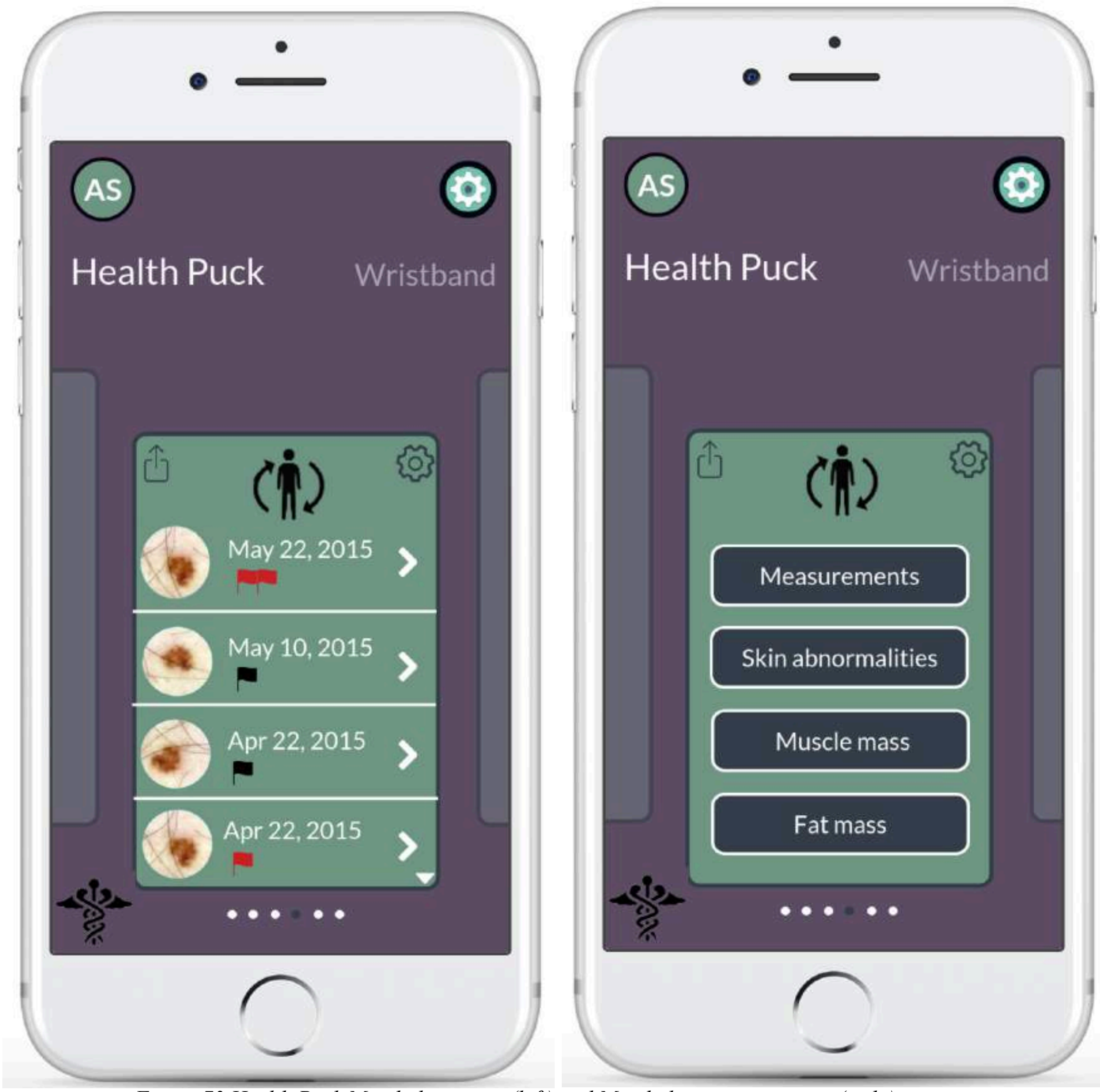

Figure 73 Health Puck Metabolism page (left) and Metabolism options menu (right)

The metabolism section of the app provides information on any skin abnormalities (moles, scars, changes in skin tone), measurements of the user, fat and muscle mass. The landing page for this metric is a timeline of skin abnormalities flagged by the health puck. It can be seen from the screenshot shown above on the left that the first and fourth moles are the same. It was first spotted on the user and it has not reduced in size or disappeared after a month. The two red flags indicate that the mole is persistent, compared to the green flags for the second and third mole, both of which have disappeared over time. The user can get more information about the moles such as location and tracking by clicking the white arrow. The user can bring up additional options by clicking the metabolism icon.

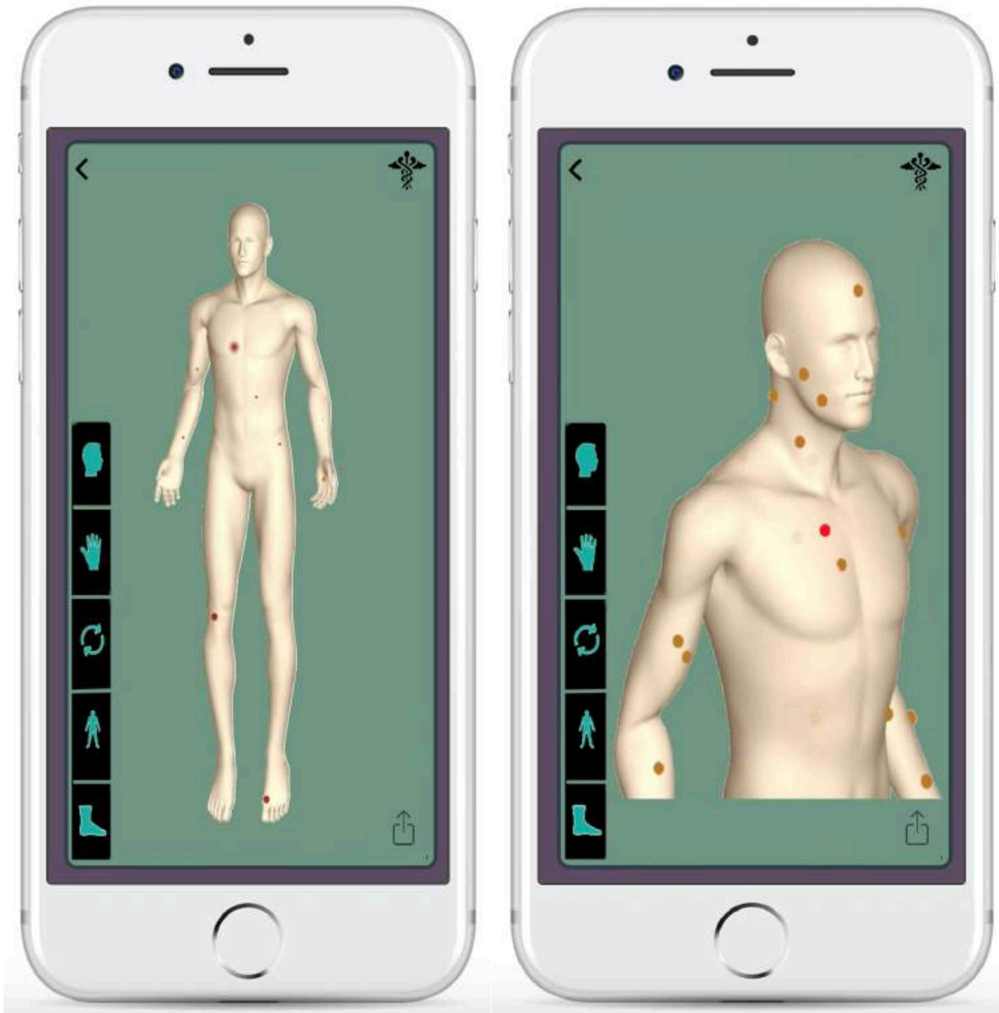

Figure 74 Skin Abnormalities body map (left) and skin abnormalities in the head region (right)

The bigger and brighter the dot, the longer the skin abnormality was noted by the system. The user can zoom into specific areas of the body with the help of the icons. The back button on the top left takes them back to the metabolism options page. Similarly, the brighter and redder the area shown in the muscle tone body map, the more change that has been noticed in those regions by the system since the last time mapping was done.

The measurements and fat mass body maps show the percentage change in the respective metrics since the last time each was measured by the system. Aevum requires a smart weight scale to be connected to the system for the measurements, muscle mass and fat mass readings to be accurate.

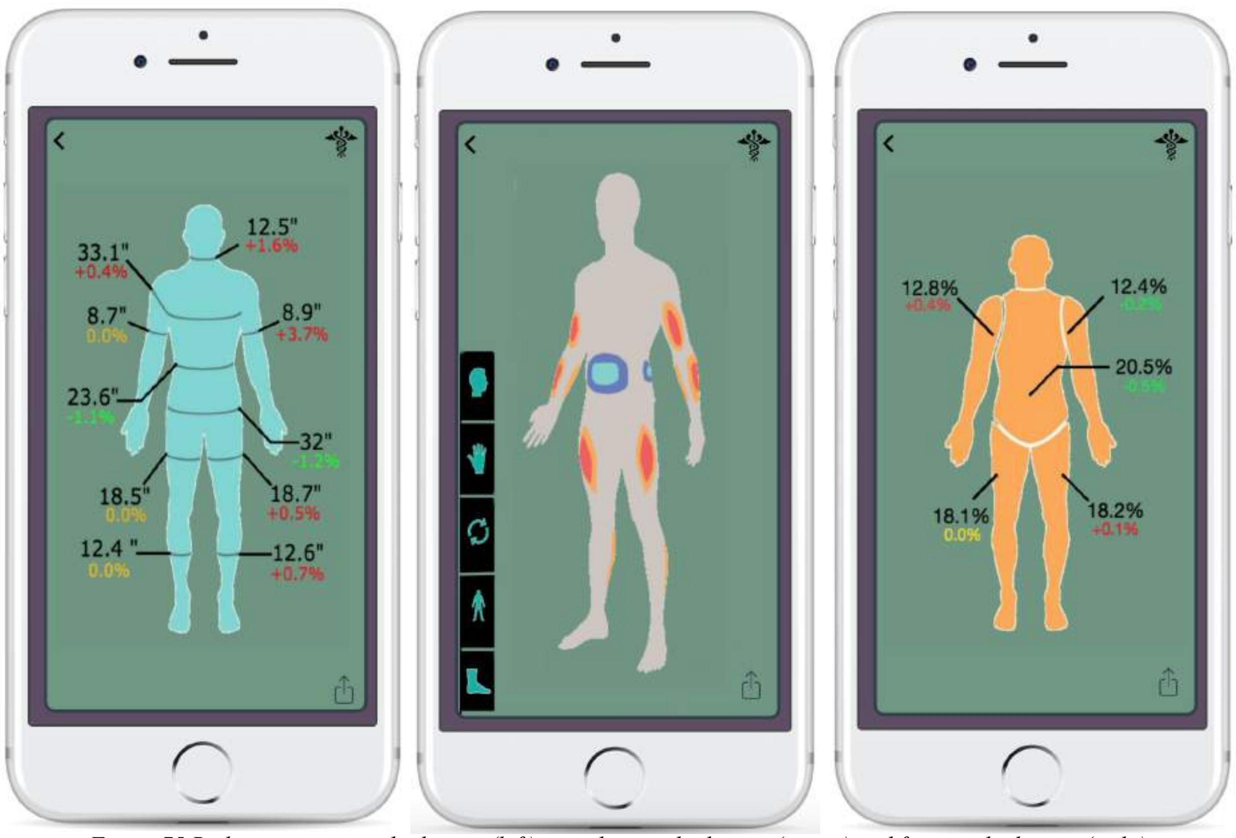

Figure 75 Body measurements body map (left), muscle mass body map (center) and fat mass body map (right)

The nutrition page in the health puck provides the calories consumed by the user for the day or week. There is also a graphic breakdown of the last meal measured by the health puck's Raman spectrometer. It shows the number of calories by food group from the last meal. The user can click on meal history to get detailed breakdown on all their meals measured on the health puck.

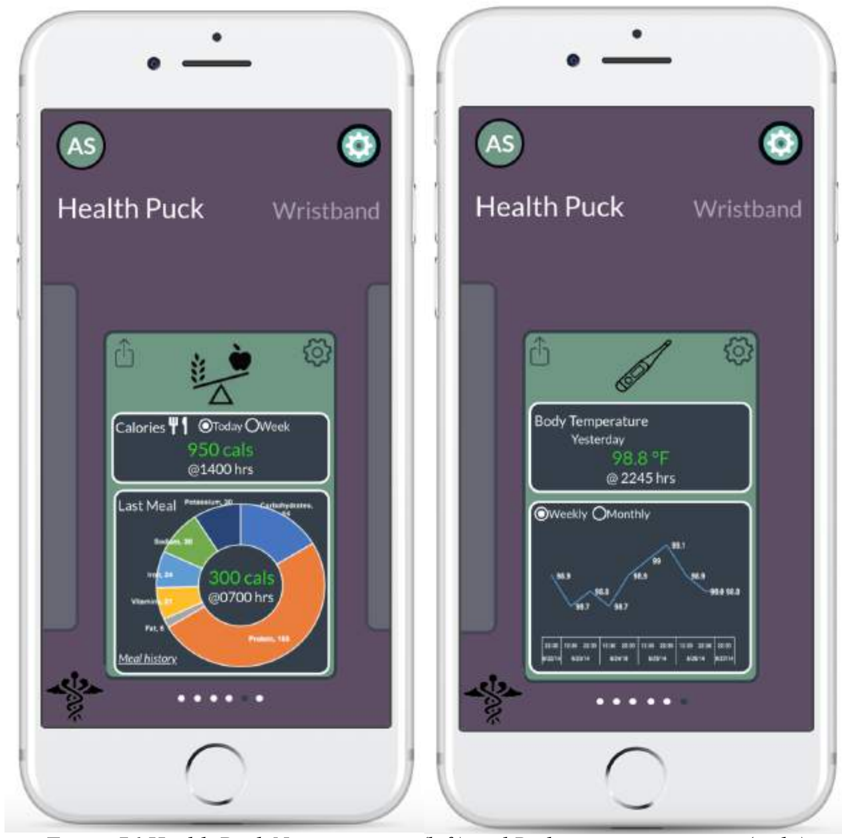

Figure 76 Health Puck Nutrition page (left) and Body temperature page (right)

The last metric measured by the health puck is body temperature. The information displayed is like the blood oxygen levels.

Wristband

The homepage for the wristband is like the homepage of the health puck. Vitals measured by the wristband can be seen on this page. The vitals measured include heart rate, resting heart rate, recovery time and blood pressure.

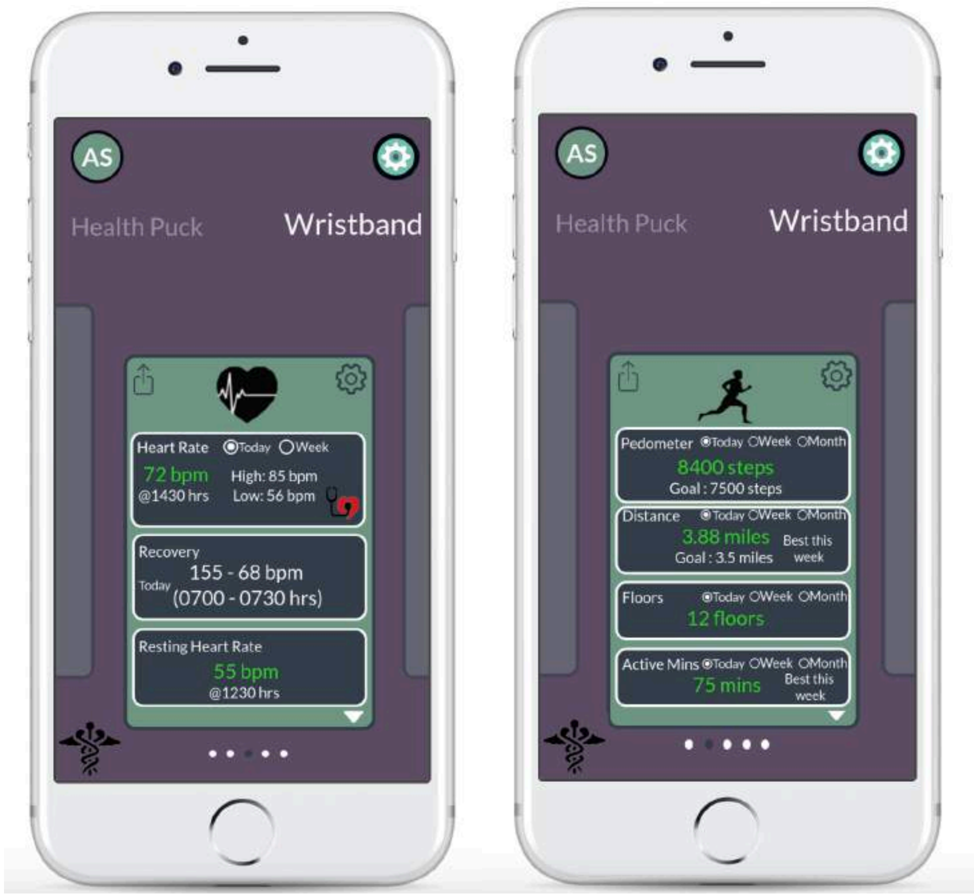

Figure 77 Wristband Vitals page (left) and Activity page (right)

It is different from the cardiac care measured by the health puck. Resting heart rate and Recovery are excellent measures of cardiac health. The user can scroll down to see their blood pressure. The user can also know their running and walking heart rate among other vital metrics. The activity page has information on the distance covered by the user, the number of steps taken, floors climbed, minutes active among other information. The information can be seen for the past 24 hours, the past week or the past month. Badges such as “Best run of the week” can be seen to help motivate the user to maintain an active lifestyle.

Figure 78 Wristband Physical Pain page

The Physical pain page is like the metabolism page. Pain is shown graphically by area, with a line graph illustrating the pain level. The user can choose the number of data points shown on the graph. The pain icon pops up a body map showing the various pain points in the body in a color gradient. The user can shift between the front and back views of the body by clicking the icon on the bottom left. The back button brings them back to the pain homepage.

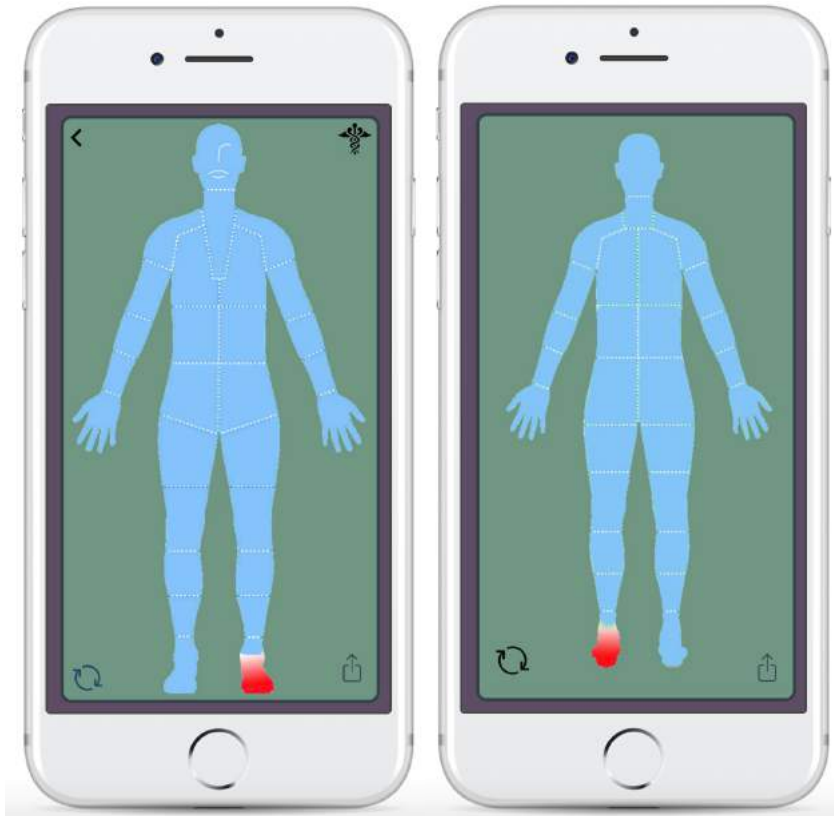

Figure 79 Physical Pain body map front (left) and rear (right)

The nutrition page in the wristband works off the bio impedance sensor and provides data on the calories consumed, calories burned and the hydration level of the user. The user can click on each window to get detailed information. The final metric measured by the wristband is Anxiety. Anxiety is illustrated by 'Mood Rating'. Mood rating is a calculation of restlessness, heart rate, idle time and GPS tracking. As the user continues to use Aevum, the system will be able to determine if the user is stress eating and use that also to calculate the 'Mood Rating'. There are three levels of mood rating; a) 1-4 is bad, b) 5-7 is normal and c) 8-10 is elated. The mood rating can be seen for the week or month. The user can click the anxiety icon to get detailed information

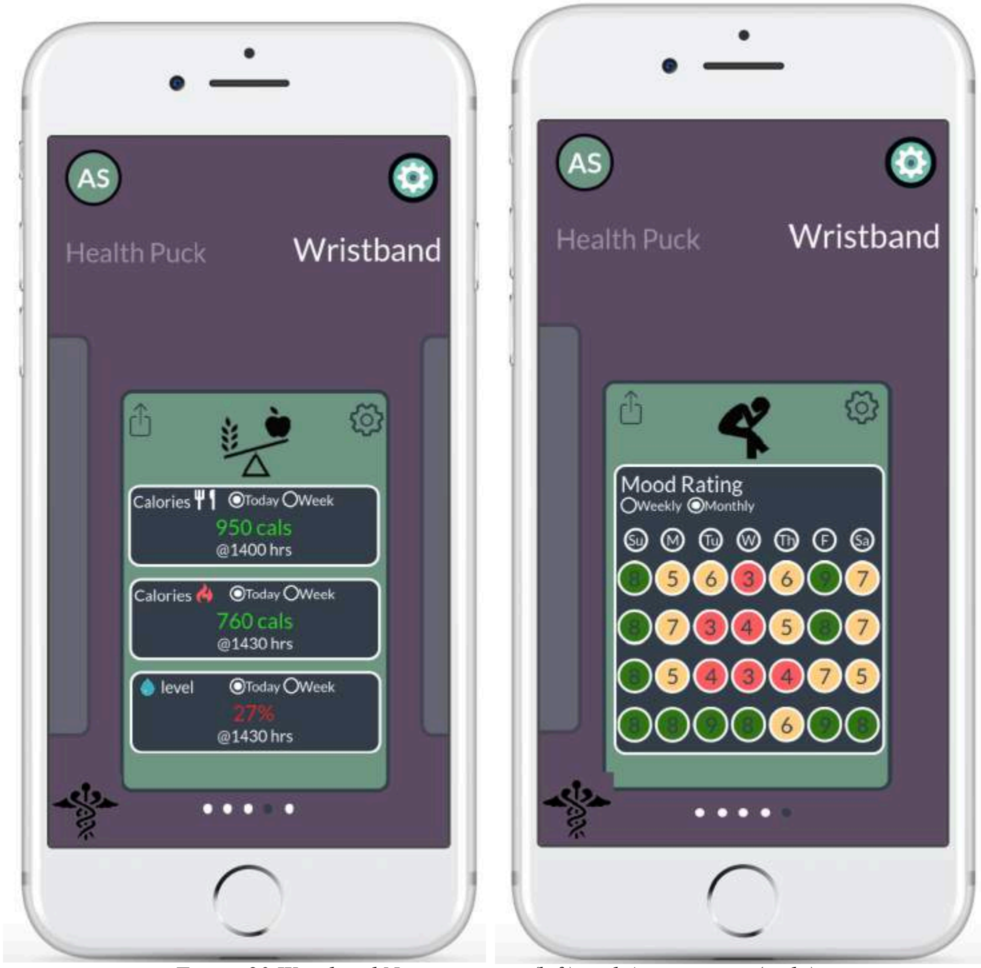

Figure 80 Wristband Nutrition page (left) and Anxiety page (right)

Interaction with Doctor

The user can share information with the doctor from each of the metric windows, from the share button near the doctor's name in the user profile or by starting a chat with the doctor. The chat window lets the user to converse with the doctor and share health data, record voice messages or send photos. In the example below, the user sends a few texts about his toe pain and shares his pill management data, hydration level data and a photo of his toe. The doctor can diagnose the user and send a prescription to the user's pharmacy.

Figure 81 Chat window with doctor

The attachment icon in the bottom of the screen is used to share data with the doctor. The user is taken to a landing page with different categories of information. They choose the category they want to share where the different metrics measured under that category are shown. The metric to be shared with doctor is then selected. The user can then choose the period of information they want to share, before sharing it. In the example below, the doctor has asked for the user's hydration level data for the past week. The user clicks the paper clip icon, chooses 'Nutrition' in the following page and the 'Body Hydration' metric under nutrition. The user chooses the week option and shares the data.

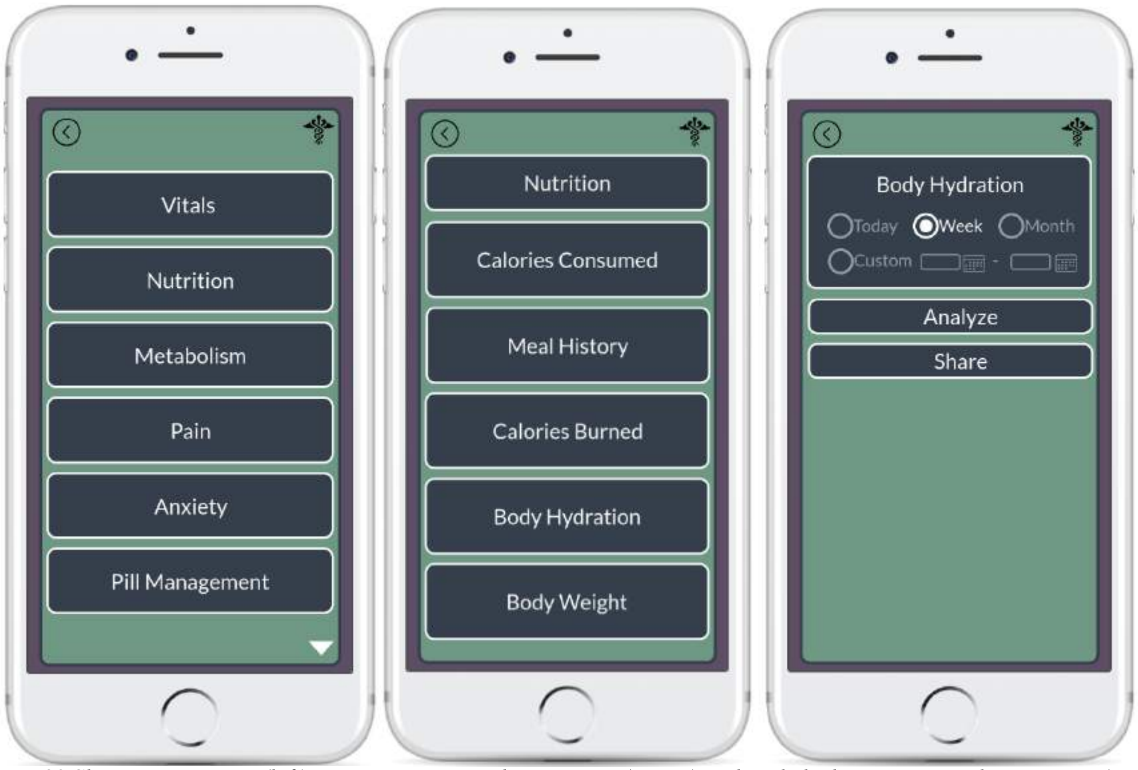

Figure 82 Sharing main page (left), Nutrition metrics sharing page (center) and Body hydration metric sharing page (right)

Doctor's End

The application on the doctor's end is also similar. The doctor has a dashboard where information is categorized by user. The doctor's profile will list some basic information on the doctor such as specialty and insurance accepted, which can be edited later if necessary. It will also list the various patients who come under the doctor's supervision. The doctor can directly reach the chat window with the patient by clicking on the message icon below the patient's name. The chat window is like the one we saw on the user's end. The doctor can see if the patient has seen a message or not.

Figure 83 Aevum Doctor's app dashboard (left) and Doctor's profile page (right)

The settings window is again like the user's settings window with 5 options;

a) ***FAQs*** – Frequently Asked Questions to help the doctor navigate through the app easily
b) ***Appointments*** – Calendar with the doctor's previous and upcoming appointments
c) ***Billing*** – Billing functionality connected to the insurance providers
d) ***Connectivity*** – Connecting to the patient's Aevum devices to get information collected on the patient
e) ***Terms & Conditions*** – Terms and Conditions about using Aevum.

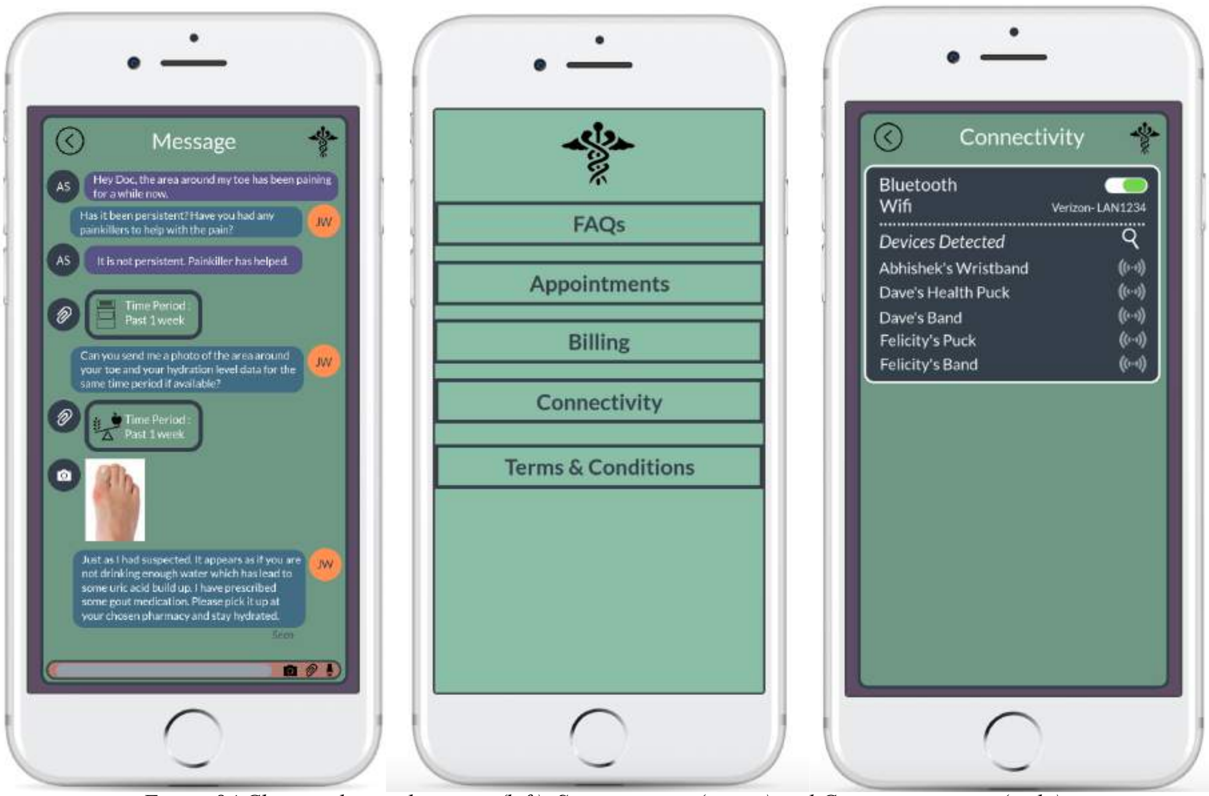

Figure 84 Chat window with patient (left), Settings menu (center) and Connectivity page (right)

As mentioned earlier, the patient can book an appointment with the doctor via the app. They can then share the data with the doctor an hour before the appointment from the app or by letting the doctor connect to the device. The 'Connectivity' screenshot above shows how the doctor would connect with the patient's device. The doctor can search for a new device if it is not detected by the app by clicking the magnifying glass icon. When the connection icon to the right of the patient's device becomes opaque white from transparent gray, it means the doctor is connected to the patient's device and can access the patient's data with an interface like the one the patient uses.

Chapter V - Conclusion

The aim was simple, it was to improve patient-doctor conversations by empowering the patients and by providing the doctors with data collected over time in non-clinical settings. The study looked at the most successful health monitoring products available in the market today and it was discovered that they did not do anything more than activity tracking. They did not provide any insight to consumers nor did they provide any support to the doctors (unless they too owned the same device).

We are heralding a new era in health monitoring technology. It is possible now to unobtrusively monitor several metrics that can help with early detection of several life-threatening conditions. Most health monitoring device manufacturers do not differ in features from one another and this is holding back technologies that could really help people from ever seeing the light of day. The most significant achievement by Apple, has been in developing the "Health Kit". The Apple Health kit connects the several health monitoring devices available into one system by adhering to protocols set by the company. This is a great move and, yet it does not do anything more than bring all the data under one application on their devices. It does not help the average consumer with any qualitative measurement nor does it help any doctor with greater insight about their patient.

Consumers are not just seeking a constant stream of quantitative output from sensors that are housed in today's devices. They want the data to give them context, they want qualitative information that provides positive reinforcement, nudges them to develop good habits and makes them aware of their shortcomings. Consumers adopt devices that unobtrusively measures data and don't want to be bothered with manual data entry. Doctors are looking for the quantitative output from sensors. They are looking for information on what triggered their patient's condition or are looking for ways to ease their conversation with their patients. It is up to the designers and product developers of today to strike the right balance between a living device that grows and adapts to their consumer's needs and at the same time provides the quantitative information that doctors need.

It is important now to empower people with regards to their health. People are always making lifestyle changes to stay healthy and the ideal way to empower them is to provide them with tools or technology that will help them understand the impact of the changes they make. Empowering users allows them to face their fears with confidence, allows them to converse better with their doctors and ask the right questions. They can remember the advice from the doctors better if they become equals in the conversation, not if it is a one-way street and they are spoken down to. Doctors will have an easier time and can concentrate on treating the patient's condition at hand than fear being judged by their patients.

Empowering the patient also requires prolonged and holistic monitoring and tracking of an individual's health. A wristband that functions as an activity tracker might be useful for the millennial, but America is getting far too old far too quickly. Sensors and other electronic devices have become cheaper and can accurately measure a great range of modalities. The tail end of the baby boom generation will soon become the elderly and they are not averse to technology. We should provide them with a system that will bring under its umbrella the various products in the market, develop heuristic algorithms that learn from each activity or interaction the user has with the environment around them, throw the latest and best artificial intelligence and machine learning modules at this problem easing the access to healthcare.

The time is ripe to move towards holistic health monitoring. Smart home health monitoring can help empower the elderly to take control of their lives and lessen the burden on the healthcare system. Aevum aims to do this exactly. It is a system comprised of two components, a home-based health puck and a wristband. It derives quantitative information as output from the various sensors and technologies built into it and converts them into qualitative insight for the user to act on. It has heuristic algorithms built in to save information tracked from the time it is setup and learns about user's actions and motives from the information. The insights provided are highly personalized for each user.

Unobtrusive measuring using the latest in high definition imaging and sensor technology, useful insights on user behavioral patterns, constantly learning from the user about them and growing with them coupled with medical infrastructure integration are some of the trademarks of Aevum. The next step would ideally be to build this proposed into a working prototype and test.

We must admit that we have erred in our attempts to empower the common man with regards to his health and well-being. This admission can help us engender our efforts to designing and developing better products as opposed to meaningless commercials. Only such a product can help in the true empowerment of not just the individual but also the complex system that encompasses healthcare. This thesis seeks to be a starting block and hopes to bring about the congruence of talents and technologies from across disciplines for an exciting and wondrous opportunity to serve the people of this world.

Bibliography

1. Bursch, B., Beezy, J., & Shaw, R. (1993). Emergency department satisfaction: What matters most? Annals of Emergency Medicine, 22(3), 586-591.
2. Matulich, E., & Finn, D. W. (1989). Determinant criteria in patient satisfaction surveys. Journal of Ambulatory Care Management, 12(3), 45-51.
3. Rosen, D. (2014). Vital Conversations: Improving Communication Between Doctors and Patients. New York: Columbia University Press.
4. Bosch, P. M., & Dietz, D. C. (2009). Minimizing expected waiting in a medical appointment system. IIE Transactions, 32(9), 841-848.
5. Mowen, J. C., Licata, J. W., & McPhail, J. (1993). Waiting in the emergency room: How to improve patient satisfaction. Journal of Health Care Marketing, 13(2), 26.
6. Survey of appointment wait times and Medicare and Medicaid acceptance rates. Retrieved from https://www.merritthawkins.com/uploadedFiles/MerrittHawkins/Content/Pdf/mha2013waittimesurveyPDF.pdf
7. Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1985). A Conceptual Model of Service Quality and Its Implications for Future Research. Journal of Marketing, 49(4), 41.
8. Bopp, K. D. (1989). Value-added ambulatory encounters. Journal of Ambulatory Care Management, 12(3), 36-44.
9. Booth, A. J., Harrison, C. J., Gardener, G. J., & Gray, A. J. (1992). Waiting times and patient satisfaction in the accident and emergency department. Emergency Medicine Journal, 9(2), 162-168.
10. Pew Research Center Health Trends. (2015, January 09). Retrieved from http://www.pewsocialtrends.org/topics/health/
11. Gallup Healthcare Polling. (2015, August 13). Who Pays for Americans' Health Insurance? Retrieved from http://news.gallup.com/opinion/polling-matters/223577/pays-americans-health-insurance.aspx?g_source=CATEGORY_HEALTHCARE&g_medium=topic&g_campaign=tiles
12. Topol, E. J. (2013). The creative destruction of medicine: How the digital revolution will create better health care. New York: Basic Books.
13. Kaiser Family Foundation Health Polling. (2014, October 01). Retrieved from https://www.kff.org/polling/
14. American Life Project. (2015, 8). PIP: Tracking for Health. Retrieved from American Life Project.
15. California Healthcare Foundation. (2013, 12). California Healthcare Foundation. Retrieved from American Life Project: http://www.pewinternet.org/2013/01/28/tracking-for-health/
16. Dvorsky, G. (2016, April 07). This Dude's Fitness Tracker May Have Just Saved His Life. Retrieved from https://gizmodo.com/this-dudes-fitness-tracker-may-have-just-saved-his-life-1769604325

17. Health Devices Fact Sheet. (2015, February). Retrieved from http://www.pewinternet.org/fact-sheet/mobile

18. Patel, S., Park, H., Bonato, P., Chan, L., & Rodgers, M. (2012). A review of wearable sensors and systems with application in rehabilitation. Journal of NeuroEngineering and Rehabilitation, 9(1), 21.

19. Gutierrez, C. (2012, May). The History of Family Medicine and Its Impact in US Health Care Delivery. Retrieved from https://www.aafpfoundation.org/content/dam/foundation/documents/who-we-are/cfhm/FMImpactGutierrezScheid.pdf

20. Geyman, J. P. (1999). Family Medicine as a Specialty. In Family practice: Foundation of changing health care. Norwalk, CT: Appleton-Century-Crofts.

21. White, K. L., Williams, T. F., & Greenberg, B. G. (2001). The ecology of Medical Care. New England Journal of Medicine, 885-892.

22. Green, L. A., & Fryer, G. E. (2002). Family Practice in the United States. Academic Medicine, 77, 87-99.

23. Dennis, S. (2013). Family Practice Triumphs by the Year 2020: What Will We Have Done Right? FAME Medicine, (33), 4th ser., 225-227.

24. Gerteis, M., Edgman-Levitan, S., Daley, J., & Delbanco, T. L. (2011). Through the Patient's Eyes: Understanding and Promoting Patient-Centered Care. Journal For Healthcare Quality, 19(3), 43.

25. Federal Trade Commission. (2007). "Electronic Health Records." *Washington D.C.: Federal Trade Commission*.

26. Kim, E., Mayani, A., Modi, S., Kim, Y., & Soh, C. (2013). Evaluation of Patient-Centered Electronic Health Record to Overcome Digital Divide. IEEE Engineering in Medicine and Biology 27th Annual Conference.

27. Tang, P. C., Ash, J. S., Bates, D. W., Overhage, J. M., & Sands, D. Z. (2006). Personal Health Records: Definitions, Benefits, and Strategies for Overcoming Barriers to Adoption. *Journal of the American Medical Informatics Association: JAMIA*, *13*(2), 121–126.

28. Horowitz, M. D., Rosensweig, J. A., & Jones, C. A. (2007). Medical Tourism: Globalization of the Healthcare Marketplace. *Medscape General Medicine*, *9*(4), 33.

29. Lober, W., Zierler, B., Herbaugh, A., Shinstrom, S., Stolyar, A., Kim, E., & Kim, Y. (2013). Barriers to the use of a Personal Health Record by an Elderly Population. *AMIA Annual Symposium Proceedings*, *2013*, 514–518.

30. Schumpeter, J. A. (2011). Capitalism, socialism, and democracy. Mansfield Centre, CT: Martino.

31. Zheng, Y. L., Ding, X. R., & Lo, P. L. (2014). Unobtrusive Sensing and Wearable Devices for Health Informatics. IEEE Transactions on Biomedical Engineering, 61(5).

32. Poon, C. Y., Wong, Y., & Zhang, Y. (2015). M-Health: The Development of Cuff-less and Wearable Blood Pressure Meters for Use in Body Sensor Networks. 2006 IEEE/NLM Life Science Systems and Applications Workshop.

33. Jeong, J., Kim, M. K., Cheng, H., Yeo, W., Huang, X., Liu, Y., Rogers, J. A. (2014). Epidermal Electronics: Capacitive Epidermal Electronics for Electrically Safe, Long-Term Electrophysiological Measurements (Adv. Healthcare Mater. 5/2014). Advanced Healthcare Materials, 3(5), 621-621

34. Liao, Y., Yao, H., Lingley, A., Parviz, B., & Otis, B. P. (2012). A 3-CMOS Glucose Sensor for Wireless Contact-Lens Tear Glucose Monitoring. IEEE Journal of Solid-State Circuits, 47(1), 335-344.

35. Grozea, C., Voinescu, C. D., & Fazli, S. (2012). Bristle-sensors—low-cost flexible passive dry EEG electrodes for neurofeedback and BCI applications. Journal of Neural Engineering, 8(2), 025008.

36. Bush, A., Borzage, M., & Coates, T. (2013). Cerebral Blood Flow and Oxygen Delivery In Response To Hyperoxia In Sickle Cell Anemia. Blood, 122(21), 2210.

37. Lymberis, A. (2004). Research and development of smart wearable health applications: The challenge ahead. Stud Health Technol Inform, 108, 155-161.

38. Jimison, H., Pavel, M., Mckanna, J., & Pavel, J. (2004). Unobtrusive Monitoring of Computer Interactions to Detect Cognitive Status in Elders. IEEE Transactions on Information Technology in Biomedicine, 8(3), 248-252.

39. Adidas. (2012). Retrieved from adidas.com/us/micoach

40. Bal, U. (2014). Non-contact estimation of heart rate and oxygen saturation using ambient light. Biomedical Optics Express, 6(1), 86.

41. Poh, M., Kim, K., Goessling, A., Swenson, N., & Picard, R. (2012). Cardiovascular Monitoring Using Earphones and a Mobile Device. IEEE Pervasive Computing, 11(4), 18-26.

42. Zhang, Z. B., Shen, Y. H., & Wang, W. D. (2014). Design and Implementation of Sensing Shirt for Ambulatory Cardiopulmonary Monitoring. Journal of Medical and Biological Engineering, 31(3), 207-216.

43. Paradiso, R., Loriga, G., & Taccini, N. (2015). A Wearable Health Care System Based on Knitted Integrated Sensors. IEEE Transactions on Information Technology in Biomedicine, 9(3), 337-344.

44. Mailonline, J. D. (2015, January 11). My Fitbit saved my life: Student discovered she had dangerous heart condition after fitness gadget she got as Christmas present revealed her pulse had tripled. Retrieved from http://www.dailymail.co.uk/news/article-3393461/My-Fitbit-saved-life-

Student-discovered-dangerous-heart-condition-fitness-gadget-got-Christmas-present-revealed-pulse-tripled.html

45. Block, J. (2015, September 24). How an Apple Watch Helped Save A High School Football Player's Life. Retrieved from https://www.huffingtonpost.com/entry/paul-houle-apple-watch_us_5601878de4b08820d91a4688

46. Banos, O., Villalonga, C., Damas, M., Gloesekoetter, P., Pomares, H., & Rojas, I. (2014). PhysioDroid: Combining Wearable Health Sensors and Mobile Devices for a Ubiquitous, Continuous, and Personal Monitoring. The Scientific World Journal, 2014, 1-11.

47. Ezzati, M., Jaacks, L., & Siegel, K. (2013). Assessment of Intervention as a tool to accelerate lifestyle change. Proceedings of the National Academy of Sciences.

48. Cherrie, J. W., Howie, R., Semple, S., & Ashton, I. (2010). Monitoring for health hazards at work. Chichester, West Sussex: Blackwell.

49. Chandrasekaran, N. (2014). Health promotion at work place - Health monitoring at work site - A logistic health appraisal. Indian Journal of Occupational and Environmental Medicine, 9(2), 62.

50. Varshney, U. (2013). Wireless Health Monitoring: Requirements and Examples. Pervasive Healthcare Computing, 89-118.

51. United States Census Bureau. (2012). 2006-2011 U.S. Census American Community Survey 5-year estimates.

52. Olea Sensor Networks. (2014, August). Retrieved from http://www.oleasys.com/connected-car

53. Gomez-Clapers, J., & Casanella, R. (2012). A Fast and Easy-to-Use ECG Acquisition and Heart Rate Monitoring System Using a Wireless Steering Wheel. IEEE Sensors Journal, 12(3), 610-616.

54. Melcher, V., Diederichs, F., Maestre, R., Hofmann, C., Nacenta, J., Gent, J. V., Žagar, B. (2015). Smart Vital Signs and Accident Monitoring System for Motorcyclists Embedded in Helmets and Garments for Advanced eCall Emergency Assistance and Health Analysis Monitoring. Procedia Manufacturing, 3, 3208-3213.

55. Poon, C. C., Zheng, Y., Luo, N., Ding, X., & Zhang, Y. T. (2014). Wearing Sensors Inside and Outside of the Human Body for the Early Detection of Diseases. Wearable Sensors, 543-562.

56. Brantan, T., Larkworthy, A., & Clarke, M. (2016). Evaluation of the practical feasibility and acceptability of home monitoring in residential homes. Journal of Telemedicine and Telecare, 11, 29-31.

57. Korhonen, I., Iivainen, T., Lappalainen, R., Tuomisto, T., Kööbi, T., Pentikäinen, V., Turjanmaa, V. (2007). TERVA: System for Long-Term Monitoring of Wellness at Home. Telemedicine Journal and E-Health, 7(1), 61-72.

58. Phillipose, M., Fishkin, K., Fox, D., & Patterson, D. (2010). CARNAC: A guide to understand daily life via ubiquitous sensors and statistical analysis. Ubihealth, 39-44.

59. Nokia Health. (2014). Nokia Health Body Cardio. Retrieved from https://health.nokia.com/us/en/body-cardio

60. Vogel, B., Wagner, H., Gmoser, J., Wörner, A., Löschberger, A., Peters, L., Frantz, S. (2014). Touch-free measurement of body temperature using close-up thermography. MethodsX, 3, 407-416.

61. Brand, M. E., Brand, T. M., & Jay, G. D. (2002). Pulse Oximetry measurements among normoxic volunteers. J Clin Monitt Comput, 93-96.

62. Poh, M., Mcduff, D. J., & Picard, R. W. (2012). Non-contact, automated cardiac pulse measurements using video imaging and blind source separation. Optics Express, 18(10), 10762.

63. Greene, D. (2012). Accuracy of Temporal Thermometers when measuring temperature of infants. Journal of Pediatric Medicine, 22-25.

64. Pompei, F. (2001). U.S. Patent No. US 6292685 B1. Washington, DC: U.S. Patent and Trademark Office.

65. Verkruysse, W., Svaasand, L. O., & Nelson, J. S. (2010). Remote plethysmographic imaging using ambient light. Optics Express, 16(26), 21434.

66. Allen, J. (2007). High Definition Imaging and its application in Clinical Physiological Measurement. Physiol Meas, 35-39.

67. Samsung Electronics. (2016, January). Samsung News Room. Retrieved from https://news.samsung.com/global/samsung-to-reveal-creative-lab-projects-for-kids-and-skincare-at-ces-2017

68. Shide, D. J., & Rolls, B. J. (1998). Fat content labelling: Consumption trends among Americans. Journal of American Dieticians Association, 993-998.

69. Scolapio, J. (2010). Prevalence and Trends in Obesity Among US Adults, 1999-2008. Yearbook of Gastroenterology, 2010, 185-186.

70. Oakes, M., & Slotterback, C. (2001). Judgements of food healthfulness: Food name stereotypes in adults over age 25. Appetite, 37(1), 1-8.

71. Provencher, V., Polivy, J., & Herman, C. P. (2009). Perceived healthiness of food. Appetite, 52(2), 340-344.

72. Ludwig, D. S., & Brownell, K. D. (2009). The case of restaurant calorie labeling regulations. JAMA, 302(4), 434.

73. Stockman, J. (2013). Changes in energy content of lunchtime purchases from fast food restaurants after introduction of calorie labelling: Cross sectional customer surveys. Yearbook of Pediatrics, 2013, 483-485.

74. Mitka, M. (2013). Flawed Data on Caloric Intake from NHANES Present Problems for Researchers and Policy Makers? JAMA, 310(20), 2137.

75. Gelder, J. D., Gussem, K. D., Vandenabeele, P., & Moens, L. (2007). Reference database of Raman spectra of biological molecules. Journal of Raman Spectroscopy, 38(9), 1133-1147.

76. Rygula, A., Majzner, K., Marzec, K. M., Kaczor, A., Pilarczyk, M., & Baranska, M. (2013). Raman spectroscopy of proteins: A review. Journal of Raman Spectroscopy, 44(8), 1061-1076.

77. Boyaci, I. H., Temiz, H. T., Geniş, H. E., Soykut, E. A., Yazgan, N. N., Güven, B., Şeker, F. C. (2015). Dispersive and FT-Raman spectroscopic methods in food analysis. RSC Advances, 5(70), 56606-56624.

78. Czamara, K., Majnzer, K., Kochan, K., & Kazcor, A. (2014). Raman Spectroscopy of lipids: A review. Journal of Raman Spectroscopy.

79. Doughty, K., Cameron, K., & Garner, P. (2014). Three Generations of Telecare of the Elderly. Journal of Telemedicine and Telecare, 2(2), 71-80.

80. Zhang, D., Chin, C., & Yu, Z. (2013). Context-aware infrastructure for personalized healthcare. Stud Health Technol Inform, 117, 154-163.

81. Jenkins, C. D. (1985). The Epidemiology of Sudden Cardiac Death: Incidence, Clinical Features, Biomedical and Psychosocial Risk Factors. Developments in Cardiovascular Medicine Stress and Heart Disease, 17-43.

82. Elashoff, J., Van Deventer, G., Kurata, J., & Billings, M. (1985). Long-term follow-up of duodenal ulcer patients. J Clin Gastroenterol, 5(6), 509-515.

83. Hyyppa, M., & Kronholm, E. (1989). Quality of sleep and chronic illnesses. J Clin Epidemiol, 42(7), 633-638.

84. Buysse, D., Reynolds, C., & Monk, T. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. Psychiatry Res., 28(2), 193-213.

85. Urponen, H., Partinen, M., Vuori, I., & Hasan, J. (1991). Sleep Quality and Health: Description of the Sleep Quality Index. Sleep and Health Risk, 555-558.

86. Pilcher, J. J., Ginter, D. R., & Sadowsky, B. (1997). Sleep quality versus sleep quantity: Relationships between sleep and measures of health, well-being and sleepiness in college students. Journal of Psychosomatic Research, 42(6), 583-596.

87. Gillman, M. W., Kannel, W. B., Belanger, A., & Dagostino, R. B. (2008). Influence of heart rate on mortality among persons with hypertension: The Framingham Study. American Heart Journal, 125(4), 1148-1154.

88. Williams, B. A., & Merhige, M. E. (2012). The prognostic association between resting heart rate and cardiac death—Myocardial perfusion defects as a potential mechanism. Atherosclerosis, 221(2), 445-450.

89. Mozaffarian, D. (2015). Effect of Fish Oil on Heart Rate in Humans: A Meta-Analysis of Randomized Controlled Trials. Circulation, 112(13), 1945-1952.

90. Nauman, J., Janszky, I., Vatten, L. J., & Wisløff, U. (2011). Temporal Changes in Resting Heart Rate and Deaths from Ischemic Heart Disease. Jama, 306(23), 2579.

91. Geddes, L. A., Voelz, M. H., & Babbs, C. F. (1981). Pulse Transit Time as an Indicator of Arterial Blood Pressure. Journal of Psychophysiological Research, 71-74.

92. McCombie, D. B. (2009). U.S. Patent No. US20100241011 A1. Washington, DC: U.S. Patent and Trademark Office.

93. Thomas, B., Ward, L., & Cornish, B. (2001). Bioimpedance spectrometry in the determination of body water compartments: Accuracy and clinical significance. Applied Radiation and Isotopes, 49(5-6), 447-455.

94. Grimmes, M. (2005). Bio-impedance sensors: A walkthrough. Journal of Biophysics, 22-26.

95. Orcam Technologies Ltd. (2014). Helping blind or partially sighted people. Retrieved from https://www.orcam.com/

96. Sensimed Technologies. (2014). Retrieved from www.sensimed.ch/triggerfish

97. PillDrill, Inc. (2014). Retrieved from https://www.pilldrill.com/

98. US Food and Drugs Administration. (2012). RFID Pill. Retrieved from https://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm584933.html

99. Qualcomm Inc. (2015, July 29). The next wave of fitness wearables will send data directly to doctors. Retrieved from https://qz.com/467145/the-next-wave-of-fitness-wearables-will-send-data-directly-to-doctors/

100. Endeavour Partners. (2015). Retrieved from https://blog.endeavour.partners/inside-wearable-how-the-science-of-human-behavior-change-offers-the-secret-to-long-term-engagement-a15b3c7d4cf3